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THE THEORY OF IMPACT AND ITS APPLICATION TO TESTING MATERIALS.

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DYNAMIC STRESSES, OR STRESSES PRODUCED BY IMPACT.

THE manner in which impact stresses are related to so-called static stresses will require careful theoretical consideration before it can be clearly comprehended. In static tests we have merely equilibrium of forces to consider, whereas in the latter must be included the momentums and kinetic energies of moving bodies.

Before taking up a discussion of the subject, it will not be out of place to review some of the well-known fundamental relations of dynamics, which bear directly upon the subject. The four ultimate conceptions of mass, force, space, and time always bear fixed relations to one another, however they may be involved. We will use the following symbols to express these conceptions:

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m = mass
f = force
s = space
t = time
v = velocity $= \frac{s}{t}$
a = acceleration $= \frac{\text{change in velocity}}{t}$
energy $(K) = f \times s$
momentum $(Mv) = m \times v$

The fundamental relation which these quantities bear to one another is given by the equation

$$a = \frac{f}{m} \tag{1}$$

In the familiar case of gravitation, which is a uniform force at small distances from the earth, the force f is the weight of any body w, the acceleration a is called by way of abbreviation "gravity" and is designated as g; the total space passed over in a given time t is the height of fall h, and v is the velocity at the end of the time t—hence from the fundamental equation (1) and the geometrical relations of space, time, and velocity are derived the laws of falling bodies:

$$v = gt$$
$$h = \tfrac{1}{2}gt^2$$
whence $v^2 = 2gh$, or $h = \frac{v^2}{2g}$
$$g = \frac{w}{m}$$
$$\text{work} = \text{kinetic energy} = wh = \frac{wv^2}{2g} = \tfrac{1}{2}mv^2$$
$$\text{momentum} = mv$$
$$w = gm = \frac{vm}{t}$$

The above laws are given in order to show the identity of gravitation with all dynamic relations. When the velocity is variable during the time t the values in which it is involved are correctly expressed only by differentials: for example,

$$\text{velocity} = v = \frac{ds}{dt} \tag{2}$$

$$\text{acceleration} = a = \frac{d^2s}{dt^2} = \frac{dv}{dt} = v\frac{dv}{ds} \qquad (3)$$

In deducing the theory of impact it is necessary to make use of certain fundamental principles. The laws of motion which apply to a single material body apply also to a system of two or more bodies taken as a unit. Imagine two free bodies approaching each other along the straight line joining their centres of gravity. These may be considered as such a system, having a mutual centre of gravity G, whose velocity along this same line is V. Let the masses of the two bodies be A and B respectively. Then the momentum of the system is

$$(A+B)\ V,$$

and its external kinetic energy

$$(A+B)\frac{V^2}{2}$$

Now no occurrence which takes place internally, that is, between the two bodies themselves, can in any way affect these two values of the system as a whole. Only an external force, produced by some outside body, can in any way change these values. After impact between the two bodies *these values remain the same as they were before impact,* it matters not whether the two bodies stick together or rebound. The velocity of the mutual centre of gravity of the system can only be changed by some external force. The relative motions of the bodies to their mutual centre of gravity, which we will designate as "internal" may undergo any amount of change, however. If they stick together after impact, or "fall dead" the "internal" kinetic energy entirely disappears, being used up in heat and other forms of vibration. This is the case with *inelastic impact.* If the two bodies are of the same shape and mass and are perfectly elastic, they will rebound after impact, each with its original *relative* velocity, but in the opposite direction, and each will retain its original internal kinetic energy. This would be a case of *perfect elastic impact.* The reality lies anywhere between these two cases.

Let us imagine A and B to be two spheres, whose velocities are v_a and v_b, v_a being greater than v_b and the direction of motion being indicated by signs + to the right and — to the left.

Then the velocity of their mutual centre of gravity is

$$V=\frac{Av_a+Bv_b}{A+B} \tag{4}$$

Before impact the *relative* velocity of A is

$$v_a-V=\frac{B}{A+B}(v_a-v_b) \tag{5}$$

to the right and the relative velocity of B

$$(v_b-V)=\frac{A}{A+B}(v_b-v_a) \tag{6}$$

towards the left. In perfect elastic impact these velocities would be the same but of opposite sign after impact. If imperfect elastic impact they will still be inversely proportional to their masses but will be reduced by some ratio as k, being respectively,

$$\frac{B}{A+B}k(v_a-v_b) \text{ and } \frac{A}{A+B}k(v_b-v_a) \tag{7}$$

[Even where the substances are perfectly elastic, it can be shown that except in the case where the bodies are similar and equal (where the vibrations are isochronous mutually) the velocities will be reduced due to the production of internal vibrations in the bodies. When, for example, two prismatic bars of the same material, but of unequal lengths, strike longitudinally end to end, the velocity of rebound of the lighter bar is the same as though it had struck a bar of its own length instead of a longer bar.] See *"The Engineer,"* London, Feb. 15, 1867. See page 344.

The actual velocities after impact would be for

$$A,\ k(V-v_a)+V=\frac{Bv_b(1+k)+v_a(A-kB)}{A+B}$$

and for

$$B,\ k(V-v_b)+V=\frac{Av_a(1+k)+v_b(B-kA)}{A+B}$$

Here it is seen that for $k=0$, or inelastic impact, the velocities of both A and B become simply V after impact, and for perfect elastic conditions $k=1$, $2V-v_a$ and $2V-v$ respectively.

Now let us consider the physical occurrences at impact. At

the beginning of contact a mutual repellent force F begins to come into play between A and B which produces a change in the relative velocities $(v_a - V)$ and $(v_b - V)$. This force F, starting from O at first contact and increasing to a maximum when both relative velocities of A and B are brought to O, then when rebound begins again decreasing until it becomes O at departure; is counterbalanced directly by the local compression of the material of both bodies at the point of contact. As a change in velocity is possible only by the action of some force which requires *time* in which to act, actual contact between two absolutely incompressible bodies is inconceivable, since an infinite force would result no matter how slowly the bodies were to approach each other. Hence, the only physical conception possible is that all bodies are compressible and that the mutual repellent force F is produced or balanced by internal stresses occurring within the substances themselves and produced by the distortions of their particles.[1] It is true that the force F is partially sustained by the inertia of the particles themselves near the surface of impact which resist the accelerations of the local compression, as well as the stresses due to their displacement or compression. This will be taken up later on. The inertia of these particles at the local point of compression causes a stress at this point wholly disproportionate to the compression which would be produced by a static force of the same value as F, and results in a wave or vibration through the bodies in the direction of the line of impact. If these waves occur isochronously in the two bodies and the material is not stressed beyond its perfect elasticity, they will react on each other in the two bodies equally and the energy be thus restored to the velocity at departure; but if these waves are not isochronous, both bodies at departure will retain a state of vibration, which detracts that much from the energy of the rebound. It is conceivable, if the velocities of the two approaching bodies be great enough, that this force F required to equilibrate the resistance of this inertia as well as the resistance of the compression of the substance alone, would produce permanent compression or indentation of the outer surfaces of the bodies during the first instant, before the complete compression had taken place. In other words the mutually repellent

[1] Strain of the surrounding medium may take the place of the actual compression, as electric repulsion, etc. See page 241.

force F is made up of two parts, one being the elastic resistance of the body to compression or deformation, f, and the other of the force necessary to produce the local acceleration of the particles compressed, f_1

$$F = f + f_1 \tag{8}$$

Hence, it might readily follow that a permanent dent in the outer surface would occur even though the force f were below the elastic limit. Evidently for given bodies, the greater the velocity of impact, the greater does f_1, become in proportion to f.

In the case of liquids and gases, the stress f is little or nothing and the compression force is entirely due to the inertia of the particles displaced, whence $F = f_1$ and the result is a wave or concussion producing longitudinal vibration.

Returning to the discussion of the total mutual repelling force F. At any instant F is exactly equal to the change in momentum produced by its action divided by the time required to produce this change:

$$F = \frac{m(v - v_1)}{t - t_1}$$

Or more exactly,

$$F = \frac{mdv}{dt} = m\frac{d^2s}{dt^2} = ma \tag{9}$$

Consequently if the time-velocity curve can be determined, the force F can be calculated for any instant. This will be taken up in the applications further on.

The ultimate particles of which matter is composed must be thought of as incompressible, in which case, as already shown, actual contact between any such particles without the action of an external force would be a physical impossibility, since no matter how slowly they approached the force generated by actual contact would be infinite since there would be no time in which for it to act. Actual contact, therefore, can never occur between these particles, and we must assume some repellent force, electrical or otherwise, acting around each particle, and forming as it were a substanceless *cushion* acting with perfect elasticity. It is necessary to theorize thus a little into the ultimate nature of matter (whether actual incompressible atoms exist or whether they are purely a conception of some other form of the intangible

ultimatum of creation, matters not here) in order to have a clear foundation for our conceptions of impact.

Now, if two bodies impinge upon each other the mutual repellent force F may be produced either by the displacements of the particles of the substance of the bodies themselves or by the compression of some intermediate substance, forming as it were a cushion between the two bodies. This cushion might be either mechanical or ethereal, as electric repulsion, for example. The latter, however, need not be considered here. When a billiard ball strikes another similar ball, for example, the force of repulsion is derived directly from the compression of the substance of the balls themselves. When a ball strikes the rubber cushion, however, the impacting bodies are the ball and the solid table, and the force is counter-balanced chiefly by the compression of the intermediate rubber cushion. If the cushion, in comparison to the other bodies may be regarded as massless, the total force F is merely proportional to the static force which would produce the same amount of compression. If the mass of the cushion is considered, then as explained on page 239, the force

$$F = f + f_1,$$

where f_1 is the force required to overcome the inertia of the particles of the cushion. When these particles receive their maximum velocities they then act as a part of the mass of the ball. Consequently the effect of these little masses is to at first increase the value of F and then when f reaches its maximum to increase its value over that which it would otherwise have. The equation may be written

$$f = F - f_1.$$

At the instant of contact $f = o$, whence $F = f_1$, and when the compression is greatest f_1 is o and $F = f$. Comparing this with the suppository case of a cushion with no mass, at the instant of contact we have $F = o$ and at maximum compression $F = f$.

The action of the mass of the cushion may be analyzed in another way. The particles to start with have no velocity relative to the table. When struck by the ball their inertia resistance f_1 causes acceleration to take place until they reach their maximum velocities, varying according to their positions, the greatest being the particle situated at the exact point of contact.

which may be assumed to equal that of the ball (centre of gravity) since we may neglect in this case the compression of the substance of the ball, the latter being very hard compared to the rubber. The acceleration of the particles of the cushion then become negative and they help instead of retard the effect of the ball.

Now if there be any way of knowing the *relative* velocities which all these particles have at the condition referred to of their greatest velocities (relatively to the table) we would be enabled to correct our formulæ for impact so as to take into account the *mass* of the cushion. (Strictly speaking, particles would not acquire the maximum velocities at the same instant, the result being in reality a wave of impulse sent through the cushion, which consequently would make it impossible to have the cushion with perfect elasticity except in a suppository case when the vibration and compression acted isochronously.) Let m be the mass of the cushion (per unit of volume) and let v be the velocity of any particle dm, then its kinetic energy will be

$$\frac{v^2}{2g}dm,$$

and the total energy of all the particles at any instant is

$$\int \frac{v^2}{2g}dm.$$

The result would be exactly the same, as though we were to assume a mass of M_c, at the point of contact and moving with the same velocity C as the ball, of such magnitude that

$$\int \frac{v^2}{2g}dm = \frac{C^2}{2g}M_c$$

or

$$M_c = \int \frac{v^2 dm}{C^2} \qquad (10)$$

the application of which will follow later.

For simplicity of reasoning let us assume that the body struck, that is the table, is so large in proportion to the ball, that its

velocities relative to the common centre of gravity, may be disregarded. Taking the example used on page 237, call the mass of the ball A, and its initial velocity both actual and relative to the table becomes v_a, since v_b and V are practically zero. After striking the cushion and overcoming the inertia of its particles, the velocity of both the assumed mass M at the point of contact and the ball will be the same and become C, so that

$$C = \frac{A}{A + M_c} \times v_a \qquad (11)$$

according to the simple law of impact between any two bodies A and M_c, page 238 equation (4).

The energy which produces the final total compression of the cushion and consequent force $f = F$ is, therefore,

$$\frac{C^2}{2g} \times (A + M_c)$$

and the difference between this value and that of

$$\frac{v_a^2}{2g} A,$$

namely

$$\frac{v_a^2}{2g} \left(\frac{AM_c}{A + M_c} \right), \qquad (12)$$

represents the exact amount of energy which has disappeared from the ball and has gone into internal vibration, heat, etc., due to the mass of the cushion. This is, of course, on the assumption of inelastic or "dead" impact between the particles of the mass of the cushion and ball. If perfect elasticity occurred as mentioned in brackets page 242, the total energy of the ball would of course finally be returned to the ball at rebound or retained in part as mechanical vibrations of the cushion. The condition of perfect isochronous impact when all the energy is returned to the ball, and none retained by the cushion, can only occur under certain conditions explained on page 344. Such cases, however, would be almost hypothetical, and in reality the conditions approach that of the inelastic impact.

The significance of the foregoing deduction to the subject in hand is at once apparent when one comprehends that ***the specimen tested by impact is in reality in the nature of a cushion between the two impacting bodies,*** namely the hammer A and the anvil B.

The *application* of these fundamental principles will be brought out in what follows. It is important, however, to have them clearly fixed in mind before proceeding further. In the testing of material by impact, the anvil B must be of such proportions that its relative velocity v_b to that of the common centre of gravity of itself and the hammer, V, may be disregarded, as otherwise a correction must necessarily be made in all of the formulæ based on this assumption. Such correction would not only complicate the subject, but inasmuch as the anvil usually rests upon another body of some substance it would be almost impossible to properly make this correction. The most exact results would be obtained by using an anvil freely suspended in the air and struck by a hammer moving horizontally. All velocities could then be taken care of. The equations given on page 238 would then be made use of in developing the results.

In order to fulfil this assumed condition in which $V=v_b=0$, equation (4), page 238, gives the relation,

$$V=\frac{Av_a}{A+B}$$

which evidently can be rendered 0 only by an infinite mass B; but it may be reduced to any desired amount by adjusting the proportions of A, B, and v_a. Moreover, the relative velocity of A is given by equation (5), and becomes

$$\frac{B}{A+B}v_a$$

and its internal kinetic energy

$$\left(\frac{B}{A+B}v_a\right)\frac{2A}{2g}$$

These values should differ by a neglible amount from the actual velocity v_a (relative to B) and the total kinetic energy

$$\frac{v_a^2}{2g}A,$$

in order that the formulæ shall be reasonably correct.

Were it possible to measure all values *relative to the motion of B*, whatever it might be, taken as zero instead of to the mutual centre of gravity G, the formulæ using these relative velocities

TABLE I.—ACTUAL AND RELATIVE VELOCITIES BEFORE AND AFTER IMPACT.

(*B* has *O* velocity to start with. Motion toward the right is +; left −)

	Value	Before impact			After impact and separation		
		A	Mutual center of gravity *G*	*B*	*A*	Mutual center of gravity *G*	*B*
Velocity	Actual	v_a	$V=\frac{A}{A+B}v_a$	O	$(v_a-V)K-V$	V	$V(I+K)$
	Relative to *G*	v_a-V	O	$O-V$	$(V-v_a)K$	O	VK
	Relative to *B*	v_a	V	O	$-v_aK$	$-VK$	O
Kinetic energy	Actual	$\frac{v_a^2}{2g}A$	$\frac{V^2}{2g}(A+B)$	O	$\left[(v_a-V)K-V\right]^2\frac{A}{2g}$	$\frac{V^2}{2g}(A+B)$	$V^2(I+K)^2\frac{B}{2g}$
	Relative to *G*	$\frac{(v_a-V)^2}{2g}A$	O	$\frac{V^2}{2g}B$	$(V-v_a)^2K^2\frac{A}{2g}$	O	$V^2K^2\frac{B}{2g}$
	Relative to *B*	$\frac{v_a^2}{2g}A$	$\frac{V^2}{2g}(A+B)$	O	$v_a^2K^2\frac{A}{2g}$	$\frac{V^2K^2}{2g}(A+B)$	O
Momentum	Actual	v_aA	$V(A+B)$	O	$[(v_a-V)K-V]A$	$V(A+B)$	$V(I+K)B$
	Relative to *G*	$(v_a-V)A$	O	$-VB$	$(V-v_a)KA$	O	VKB
	Relative to *B*	v_aA	$V(A+B)$	O	$-v_aKA$	$-VK(A+B)$	O
F	Mutual repellant force.	$\frac{d(v_a'-V)}{dt^2}A$	=	$\frac{d(v_b'-V)}{dt^2}B$			

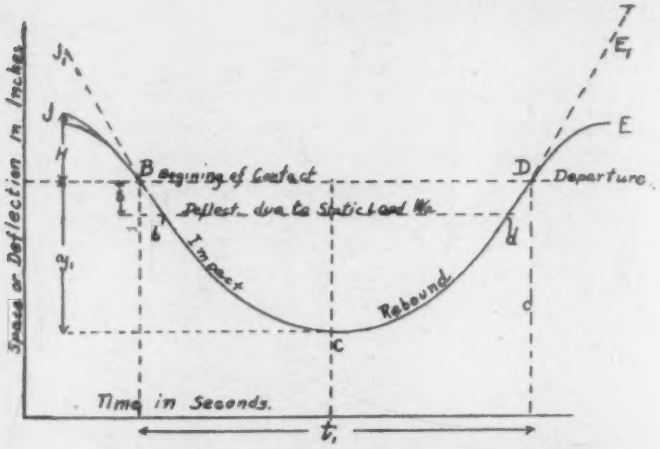
K is a coefficient representing the elasticity of the impact. It is the ratio of the relative velocity after impact to that before. For "dead" impact $K=O$; for perfect elastic isochronous impact $K=I$.

would give correct results, as may be seen by an examination of the accompanying table, with the exception of the force F which must always be referred to the mutual centre of gravity; the error referred to above, however, arises from the inability to take such measurements practically and from a lack of being able to determine the effect of the body upon which the anvil rests, upon the motions of the anvil.

Let us examine first the relations between the various quantities of an impact test graphically, and then proceed to develop formulæ of the time-space curve and of the inter-relations of the values.

Consider first a rectangular beam, of wood, or metal, or whatever material is to be tested, lying horizontally on the anvil B and supported freely at its ends, and let it be struck at the centre by a falling hammer A. For simplicity let us first consider this beam as *massless* as well as weightless.

FIG. 1.



Time-deflection curve, massless beam, within the elastic limit.

Take the velocities as relative to the anvil, as explained above, or assume the mass of the anvil so great that its motion may be taken as zero. Let the motion of the centre of gravity of the hammer A be plotted as in Fig. 1, with space as ordinates and time as abscissæ. If the hammer start at some point J and fall freely the distance H before striking the beam, the curve

JB will be a parabola, or if its velocity be uniform its motion would give the straight line J_1B. Impact with the beam begins at B, and, assuming the beam as massless, the only resistance offered to the momentum of the hammer will be the bending stress of the beam, which will be the force F. The motion curve then becomes BC. The resisting force starting with O at B increases in proportion to the deflection of the beam until the maximum value is reached at C. (In this case let the elastic limit of the beam be not exceeded). It is this force F which overcomes the momentum of the hammer A by producing a negative acceleration until the momentum is reduced to O at C. Rebound then begins. If the beam is perfectly elastic, the force F continuing to act will restore exactly the same amount of momentum to A, and in the same manner, but in the opposite direction that it had at the beginning of contact. The curve will be CD. At D departure takes place (the beam being considered as massless).

The total mutual repellent force F acting on the beam, between the hammer A and the anvil B is at any instant equal to

$$F = \frac{d^2S}{dt^2}A = \frac{dv}{dt}A$$

where S is the space traversed by A and v is its velocity at the instant under consideration. (Strictly, S is the space which A moves in relation to the motion of the mutual centre of gravity of the hammer and anvil, and it would be also exactly equal to

$$F = \frac{d^2R}{dt^2}B$$

where R is the space which B moves relatively to the same point at the same time.) If S is in feet t in seconds, and $A =$ (weight in pounds $\div$ acceleration of gravity in feet), then F is given in pounds, by the last formula.

If the force of gravity is to be considered, as well as the initial velocity of A at impact, then this formula should be written

$$F - W_a = \frac{d^2s}{dt^2}A = \frac{dv}{dt}A \qquad (13)$$

where W_a is the weight in pounds of the hammer A. This

could be avoided by having the hammer move horizontally instead of falling vertically.

Examining Fig. 1, it will be noted that the acceleration of the hammer from J to B is equal to g and is produced by the uniform force W_a. From B to D it is produced by the force $W_a - F$, and becomes negative as soon as the value of F begins to exceed W_a. This is at the point of reverse curvature, since the acceleration

$$\frac{d^2s}{dt^2}$$

is zero, and evidently occurs at the point b or the deflection which would be produced by the static load W_a. In horizontal motion the change would occur at contact, B. It should be remembered that while W_a is a constant force, F is a variable ranging from O at B to a maximum at C and again to O at D.

Whenever

$$\frac{d^2s}{dt^2}$$

becomes a maximum the force F becomes a maximum, and this evidently occurs at the sharpest part of the curve, which in this particular case is at C.

The value of F at any instant may, therefore, be determined from the curve

$$F = \frac{d^2s}{dt^2} \times A + W_a$$

The curve is usually obtained by some mechanical device, by means of which the falling hammer makes a tracing on a uniformly revolving drum.

Assuming the stress in the beam to be proportional to its deflection, *i.e.*, that the static conditions hold true under rapid distortion, we can determine the force F from the ordinary static equation if the deflection is known at any point, for

$$F = \frac{\Delta \times 46 \times EJ}{l^3} \qquad (14)$$

where Δ is the total deflection at the centre (within the elastic limit) E the modulus elasticity in bending, J the moment inertia of the cross section and l the span. Let H be the distance (cor-

rected for friction) the weight falls before touching the beam, or

$$v_a = \sqrt{2gH}$$

its velocity, then

$$W_a(H+\Delta) = W_a\left(\frac{v_a^2}{2g}+\Delta\right) = \frac{1}{2}F\Delta \tag{15}$$

Whence

$$W_a(H+\Delta) = \frac{24EJ\Delta^2}{l^3} \tag{16}$$

which for rectangular beams is

$$\frac{2Ebh^3\Delta^2}{l^3} \tag{17}$$

from which E may be calculated. And

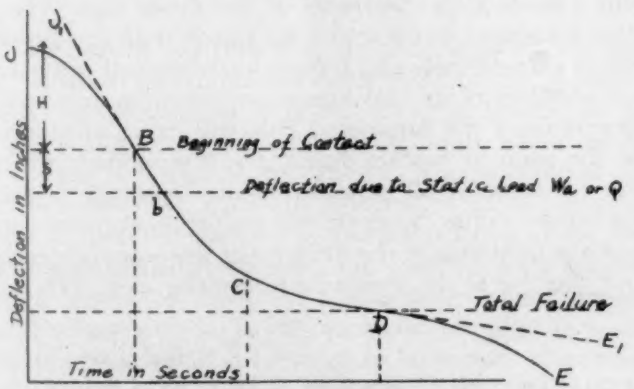
$$W(H+\Delta) = \frac{2Rbh^2\Delta}{6l} \tag{18}$$

from which the extreme fibre stress R may be obtained.

If the beam is stressed beyond its elastic limit, however, the ordinary formulæ do not apply and the force F must be found from the curve in the manner just explained.

If the force F of the impulse becomes sufficient to cause

FIG. 2.



Time-deflection curve, beam stressed beyond the elastic limit.

complete failure of the specimen, the conditions are those shown in Fig. 2.

The first part of the curve JB is the same as before. The velocity or momentum of the hammer is, in this case, not entirely overcome by the resistance F of the beam, so that at failure the hammer retains a portion of its velocity as indicated by the tangent line DE_1. If the hammer works vertically in free fall, instead of horizontally, then the curve DE is again a parabola of free fall. In this case the force F becomes a maximum at some point C when the curvature is sharpest, and must be determined from the curve by

$$\frac{d^2s}{dt^2}$$

since there is no means of calculating it mathematically. When F is thus determined the maximum strength values may be calculated in the usual manner, formula (14).

The difficulty of comparing the values of the stresses in impact tests with those which occur in static tests (*i.e.*, where the momentum of the load does not factor) lies in the difficulty of accurately determining the value of the force F in the former. Comparisons of the total *work* required to rupture a specimen, or to produce a given deflection are comparatively simple.

The deductions thus far have been made on the assumption that the beam was massless as well as weightless. If now we take into consideration the *mass of the beam itself* (but still neglecting its weight which would not factor at all in a horizontal test, and to an extremely small degree in a vertical test) its own inertia is added to its internal stresses of distortion in overcoming the momentum of the hammer. This will exert a compression force at the point of contact during the first moment of impact until the velocities of all particles of the beam are brought to their maximum values, as explained on pages 239 and 240. If this force due to inertia of the particles of the beam be designated as f_1 and that due to the resistance to bending as f, then

$$F = f + f_1.$$

The force f_1 becomes O again in inelastic local deformation as soon as the condition of maximum velocities of all the particles has been reached, and those immediately at the point of contact will be moving with the same velocity as the hammer A. The

mass of the beam will then be acting the same as though a proportion of it were simply a part of the hammer. If we assume that the beam bends under impact with the same form of curve which it would have under a static stress, the inertia of the particles can be readily determined, since their velocities at any instant would be proportional to their deflections. We may, therefore, in order to simplify this problem assume that the mass of the beam be replaced by a hypothetical mass m_o placed at the point of contact, which will have the same effect, both in its inertia and energy as the original mass of the beam. As a basis of this assumption, the following principle is made use of:

If we have any train of mechanism connected in any manner whatsoever (unknown) but so that the relative velocities of all of its masses are known and are determined by the kinematical form of the mechanism, and the resultant force F be known acting on any one mass which is the cause of the various accelerations of all the parts; it follows that the resultant force acting on each separate one of the masses is inversely proportional to its velocity ($f = am$). Any part m_1 may, therefore, be changed in its position so as to move with a new velocity v_2 provided it be changed in mass in inverse proportion to the squares of the original and new velocities,

$$m_2 = m_1 \frac{v_1^2}{v_2^2}$$

without altering in any way the kinetic energy of the system nor the velocities of any of the other parts of the system, still acted upon by the original force F. In other words, the force F acting for time t would produce the same effect upon the altered as upon the original mechanism. The momentum of the changed part, however, would be different, which is nevertheless of no consequence, the point being that the reaction of the altered and the original mechanism upon the external body producing the motion would be identical.[2] The beam under impact is such a mechanism since its points of support are fixed in position, and its curve of bending is assumed to be known. Let us suppose the beam to be divided into thin cross sectional disks differential x in thickness. The velocities of these disks at any

[2] See "Mechanical Relation of Force and Mass" by H. D. Tiemann in Stevens *Indicator*, October, 1901.

instant will be proportional to their deflections. Let m be the mass of unit length of beam and let m_o be the hypothetical mass to be placed at the centre, which is to replace in effect the original mass of the beam. Taking ordinates at one point of support, let y be the deflection for any distance x from the support, and y_1 be the deflection at the centre, distance $x = \frac{1}{2}l$. Then we may obtain according to the above argument.

$$m_o y^2_1 = \int_o^l my^2 dx \tag{19}$$

The equation of the curve of a prismatic beam supported at the ends and loaded at the middle is

$$y = \frac{Px}{48EJ}\left(3l^2 - 4x^2\right)$$

$$y_1 = \frac{Pl^3}{48EJ}$$

and

$$m_o = \frac{(48EJ)^2}{P^2 l^6}\int_o^l m\left(\frac{P^2x^2}{(48EJ)^2}(9l^4 - 24l^2x^2 + 16x^4)\right)dx = \frac{17}{35}ml \tag{20}$$

This is the quantity which should be used for m_1, as replacing the original beam both for kinetic energy and *also for momentum*, and *not*

$$\frac{1}{y_1}\int_o^l mydx$$

for the momentum, as has been wrongly used. These values of m_o were derived by Cox in 1848.

Actually the form of the curve of the beam under impact is different from that in a static test, approaching more or less the sinusoid of vibratory waves, depending upon the relative ratios of the masses, intensity of impact, and length of span. Dr. A. Gessner in tests upon cast-iron beams ("Ueber die Beanspruchung Freiaufliegender Träger durch Stoss," Wien. 1906) in which the weight of the specimens was less than a fourth the weight of the hammer, finds that the actual curves obtained are practically identical with the theoretical. He uses

for the reduced mass $\frac{1}{2}$ M for kinetic energy and $\frac{5}{8}$ M for momentum, M being the mass of the beam.

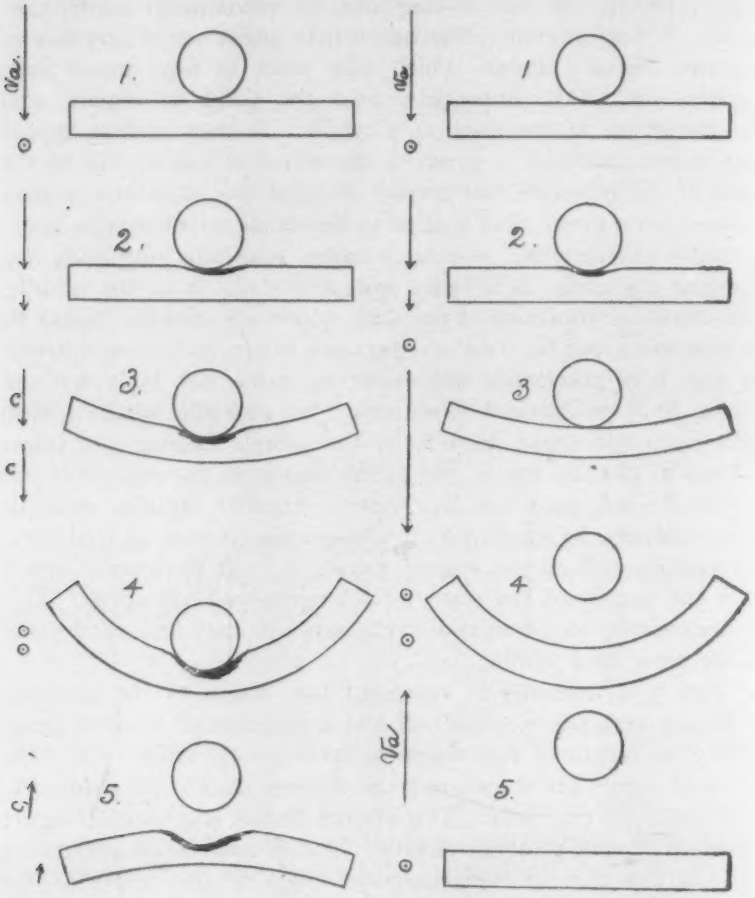
Before developing the mathematical formulæ for impact tests where the mass of the beam is taken into account, let us examine graphically by the aid of diagrams the phenomena which take place. A diagrammatic illustration may assist our conception of the two distinct actions which take place in any impact test, namely, the local compression near the point of impact, and the distortion of the body as a whole. It may at first appear that undue attention is given to the effect of the inertia of the mass of the specimen, but further thought will show that it may become very great, and that it is the cause of otherwise inexplainable phenomena. For an instance, take any long stick fastened at the ends, as a fence rail, and strike it in the middle. The result is vibrations of the stick which are *entirely caused by its own mass and the local compression produced in consequence.* In fact it is practically impossible to strike any body without giving to it mechanical vibrations. So also the wear of steel rails from the slight impacts of the wheels causing the upper surface to swedge out, is due to the inertia of the rail itself and not to the bed upon which it rests. Another familiar example is the difficulty in starting a very long train of cars, as coal cars; the sudden pull of the engine causes a local elongation which runs the length of the train as a longitudinal vibration. This is due entirely to the inertia of the separate cars and not to that of the train as a whole.

Fig. 3 is intended to represent five stages of the progress of impact between a metal ball and a rectangular wooden beam resting by means of two supports upon a solid anvil. Only the essential points are shown and the dimensions are purposely exaggerated for clearness. The arrows to the left of each figure represent the respective velocities of the centres of gravity of the ball and that of the transposed mass or the centre of the beam, the length of the arrows being proportional to the respective velocities at the stage represented.

At stage 1 the ball has its initial velocity v_a and the beam O. The first resistance to the momentum of the ball is that of the inertia of the beam only, as no bending has taken place. This resistance, which we will designate by the force f_1 produces the

local compression, as shown at stage 2. At this instant the velocity of the ball is being reduced and acceleration is beginning in the beam due to the force f_1. At stage 3 the local compression and consequently f_1 have reached their maxima and the velocities

FIG. 3.



of both the centre of the beam and ball are the same. The momentum of the ball has been reduced since stage 2 by the action of both the force f_1 and also by the force f due to the bending of the beam.

If we call the force retarding the momentum of the ball at

any instant F, then during contact

$$F = f_1 + f$$

F is also the force producing the local compression.

The common velocity is now

$$C = \left(\frac{A}{A + m_o}\right) v_o$$

What happens next depends upon whether the local compression is permanent or inelastic or if it recovers as elastic. In the inelastic case, shown to the left part of Fig 3. the indentation remains and the ball and the beam act together as one body, having the same velocity, until departure takes place. Bending continues until the mutual velocity is reduced to zero, as in stage 4. The force acting since stage 3 was passed, being simply $F = f$. Rebound then begins, the two bodies moving as one until departure takes place. When this happens the inertia of the beam with its upward velocity, carries it beyond the initial horizontal position while the ball leaves the beam with its velocity C_1. Stage 5 is a short time after departure. At impact a loss of energy occurred, which produced the local indentation, and which if the compression is inelastic is dissipated in heat or molecular vibrations; the amount lost is

$$\frac{v_o^2}{2} A - \frac{C^2}{2}(A + m_o) = \frac{v_o^2}{2}\left(\frac{A m_o}{A + m_o}\right)$$

At departure a further loss occurs to the ball, or rather is not restored, which gives the beam its vibrations, for the velocity of both together is

$$C = \left(\frac{A}{A + m_o}\right) v_o$$

and the combined energy is

$$\frac{v_o^2}{2}\left(\frac{A^2}{A + m_o}\right)$$

of which amount the ball retains

$$\frac{C^2}{2} A = \frac{v_o^2}{2}\left(\frac{A^3}{(A + m_o)^2}\right)$$

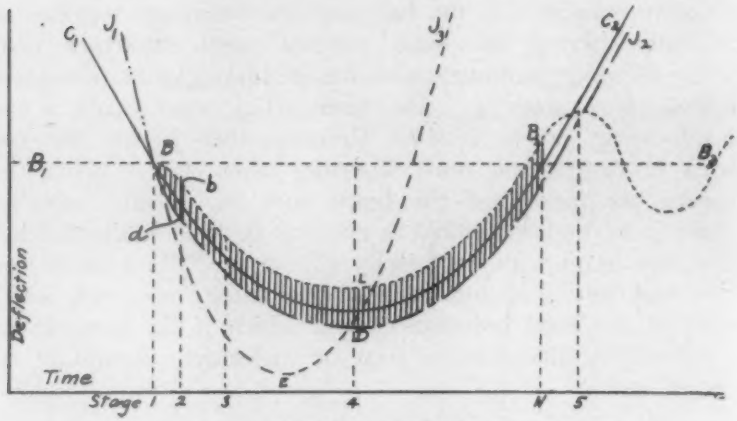
and the beam retains in vibration

$$\frac{C^2}{2}m_o = \frac{v_o^2}{2}\left\{\frac{A^2 m_o}{(A+m_o)^2}\right\}$$

We will assume for simplicity that all the motions are horizontal instead of vertical, thus doing away with the influence of the weights.

If we represent these conditions of inelastic impact in a diagram with time for the ordinates and space or deflection for the abscissæ, a curve similar to that of Fig. 4 is obtained.

FIG. 4.



Inelastic or "dead" impact.

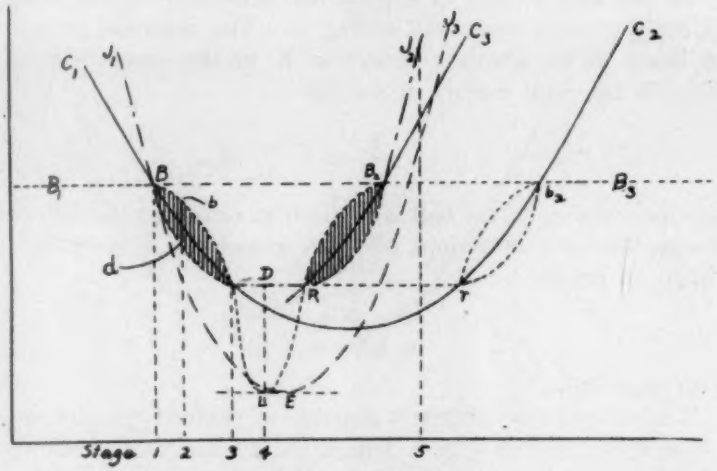
In this figure and the following ones which are similarly labelled throughout, the dash-and-dot line represents the motion of the centre of the ball, the dotted line that of the centre of the beam, and the solid line that of the mutual centre of gravity of the ball and the hypothetical mass m_o. The dash line J_1BDJ_2 is the motion of the centre of the ball if the beam were massless and perfectly elastic. In all cases J_1B is the motion of the ball before impact, and B_1B that of the beam. Impact is supposed to occur at B. The stages shown in Fig. 3 are indicated by numbers on the lower line. The amount of local compression is evidently the vertical ordinate of the shaded portion.

In Fig. 4 when impact occurs at B the local compression must rapidly increase to a maximum due to the force f_1, in order to give to the beam its bending velocity C. The velocity JB

of the ball is correspondingly reduced, so that at the line *bd* both are moving together with the same velocity *C*, indicated by the tangents to the curves. The local compression is then *bd*, which remains permanently in this case. The two curves are then parallel to B_2. Departure occurs at stage *N*, the hammer continuing with its velocity *C*, and the beam vibrating as indicated by B_2B_3.

Whether impact is dead or elastic makes no difference in the first part of the curve as far as *bd*. If the local deformation be permanent the subsequent motions will be those of Fig. 4 just explained, the beam retaining vibration.

FIG. 5.



Isochronous elastic impact.

In the case of this deformation being elastic, further action takes place between the ball and the beam due to the continuation of the force f_1, in the recovery of the deformation. This effect can be only to *retard* the motion of the ball more than in the case of dead impact just discussed, with the consequent acceleration of the motion of the beam. The result must inevitably be *separation* of the two, since the force of deflection *f* can not retard the velocity of the beam more rapidly than it does the combined mass of Fig. 3, *i. e.*, the resulting force *F* tending to deflect the beam must be greater than in the case of dead impact.

Two general cases may therefore be conceived to occur in elastic impact. First, it is theoretically possible that the secondary impact after the separation may occur as represented in Fig. 5 in such a manner that the final separation will again reduce the velocity of the beam to zero at departure. This we will designate as "isochronous elastic impact." Whenever separation occurs the velocity of the ball remains uniform, and the time is reduced since the time-space curve during the interval is that of free vibration of the beam alone. During contact in every case whether elastic or dead the curve of the mutual centres of gravity is always the same, being that of the combined mass, C_1C_2.

In the case shown in Fig. 5 the deflection of the beam is evidently greater than that in Fig. 4. The potential energy in the beam at its greatest deflection L in this case, Fig. 5, is evidently the total energy of the ball

$$\frac{v_a^2}{2}A$$

since the velocity of the ball is reduced to zero, and the difference between the two deflections of Figs. 4 and 5 is exactly the lost energy at impact =

$$\frac{v_a^2}{2}\left(\frac{Am_o}{A+m_o}\right)$$

as on page 256.

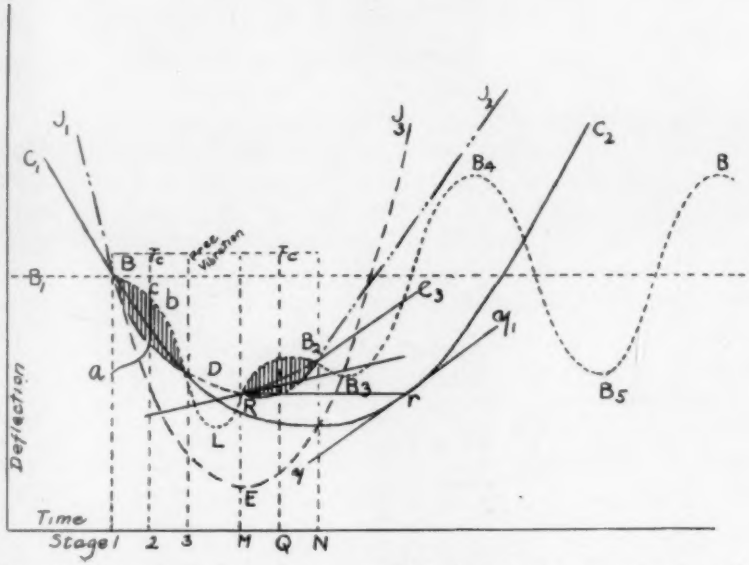
The second case which is possible in perfectly elastic impact is that illustrated in Fig. 6, where the motion of the beam and that of the local compression are not isochronous, in which case the beam will retain vibrations also. It is therefore possible to have perfect elasticity and yet have the beam retain vibrations and the velocity of rebound of the ball be less than that of impact. In fact this is the general rule, the other case being almost a hypothetical condition.

The velocity of the ball at rebound B_2J_2 can evidently never reach that of impact JB, except in the instance given in Fig. 5, since the direction of its curve at B_2 must be less steep than it is at B. The extra energy of the elastic compression

$$\frac{v_a^2}{2}\left(\frac{Am_o}{A+m_o}\right)$$

may cause increased remaining vibrations of the beam or increased velocity of the ball at departure, or both, above that of dead impact, depending upon the total deflection of the beam. If this deflection be greater than that of Fig. 4, dead impact, the extra energy must go into the final velocity of the ball; if less than Fig. 4 it goes into increased vibrations of the beam. So we may have a case of elastic impact where the final vibrations of the beam are greater, and the energy of the ball less, than in the case of dead impact.

FIG. 6.



Non-isochronous elastic impact. Final velocity of ball, B_2J_2 is less than in dead impact C_1C_2 vibrations of beam B_3B_4 are greater.

In any case the total deflection of the beam is such that its potential energy plus the kinetic energy remaining in the ball at the same instant is equal to the restored energy of the ball at departure plus that of the remaining vibrations of the beam.

(To be continued.)

FRANKLIN INSTITUTE

(Stated meeting, held Wednesday, June 16, 1909.

THE DEVELOPMENT OF MODERN ROAD SURFACES.

BY

W. H. FULWEILER.

(Concluded from September, page 183.)

SURFACE COATING WITH TARS.

The most general process, however, for the suppression of the dust nuisance is the use of a surface coating of tar. From the chronological table of its development, we shall see that although its general use came about the same time as the use of oil, experiments had been made with it in France twenty years earlier, yet on account of the universal use of gas the economical supply of tar was not limited by geographical considerations, so that it at once secured a wide field of usefulness. The following table gives the general development of its use:

DEVELOPMENT OF TAR COATING.

1867. Chas. Tellier, in France, first proposed the use of tar as a surface treatment on roads.

1871. A. M. Francon, at Auch, applied a coating of cold tar, and then fired it to secure a better penetration.

1880. Cristople, at St. Foy le Grande, and Lavinge, at St. Gaudens, made some experiments with cold tar.

1886. Experiments were made at Melbourne, Australia, with considerable success.

1888–1892. Further work was done at St. Gaudens by Cristople.

1894. A short piece of road at Montclair, N. J., was treated with coal tar, and screenings were rolled in. The first use of this method.

1895. The first general experiments, where all conditions were noted and considered by Guardeau in France. He used both hot and cold tar, and noted the better effect with hot tar.

1900. Rimini, an Italian road engineer, patented the use of coal tar mixed with a drying oil. This gave a quick, smooth finish, but did not last very well.

1901. Drs. Schottelius and Guglieminetti made their classical experiments at Monte Carlo and Nice, and determined the essentials for successful results.

1902. The League for the Suppression of Road Dust was formed with headquarters in Paris. They succeeded in interesting the French Government, so that systematic experiments were undertaken in the Department of Seine, Seine et Marne and Seine et Oise. This same year the success attained at Monte Carlo and Nice led to the tarring of the whole road from Cannes to Mentone.

1903. The work was now undertaken on some of the suburban roads that were largely used by motors about Paris; at St. Cyr and in and around Versailles.
1904. The roads in the Bois de Bologne were tarred, and the Boulevard Maillot and Avenue de la Grand Armée.
1905. The use of tar mixed with tar oils so that heating was avoided, was widely tried in France.
1906. The use of tar became quite general in France, England, and was commenced in America.

There are several reasons why the use of tar was more general than that of oil. As mentioned before, it could be more easily procured, it was cheaper, and it was more widely applicable to different kinds of road surfaces, particularly to the broken-stone roads of Continental Europe, and it gave much better results than the paraffin base oils first used on the Continent.

Again, the object of Dr. Guglieminetti's experiments were, primarily, to better the hygienic conditions that resulted from the dust clouds raised by traffic.

They found that there was a great increase in the number of microbes per cubic centimeter in the air near roads that were frequented by automobiles, and that while the use of petroleum oils that were first experimentally used decreased the number of microbes when first applied, yet their value as antiseptic agents soon diminished almost to zero. So that they were searching for some antiseptic agent that would have a more permanent value. The value of tar in this connection was well known, as it had been used for many years in treating various plant diseases, and this led to its trial at Monte Carlo, with surprisingly successful results.

When we consider the methods of applying the tar, we find that they may be divided into three general heads.

1. Painting the road surface by brushing with a hot coating of coal tar and dusting it lightly with sand. In general use in France.

2. Painting the surface by machine or with a very light coating of oil tar or thinned coal tar, and dusting with sand. This is generally used in England.

3. Coating the surface with a fairly heavy coating of hot tar or tar compounds, and then covering with a light coat of screening and rolling. This is the general system used in America.

In reviewing these methods, we should bear in mind the objects to be attained. In the first place, we wish to hold the

surface dust in place so that it may perform its function of retaining the stones composing the wearing surface in their proper position to reinforce this matrix against the shearing strain put on the surface by the passage of motor cars, and to form a waterproof coating on the road surface protecting it from the action of the atmosphere, and thus minimizing the formation of mud.

We cannot, of course, prevent the formation of dust from detritus dropped on the road by traffic, but when first applied the tar will absorb a considerable quantity of it, and in this action is surpassed by the heavy oils.

There have been an innumerable number of variations proposed and tried, so that it would be almost impossible to even review them all, so that only the most successful methods coming under the three foregoing heads will be gone into. The first method was the outgrowth of the experimental work done by the French engineers, and the general conclusions laid down by Dr. Guglieminetti seem to cover the subject so thoroughly that they will be repeated here.

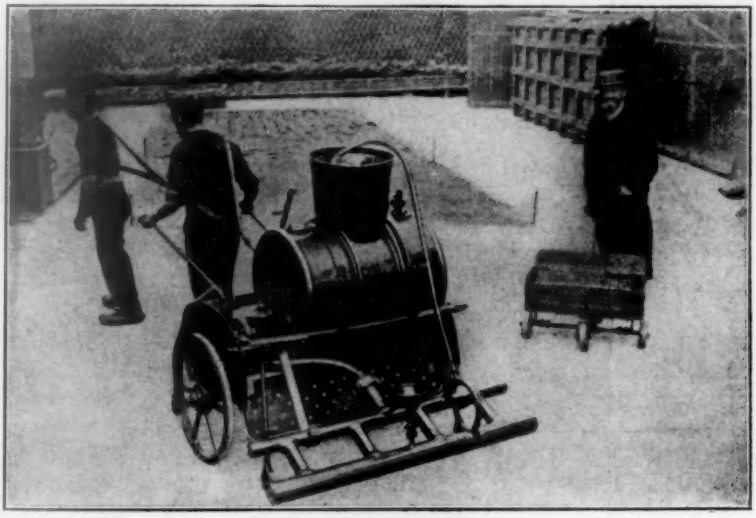
The weather should be clear and dry with an air temperature not lower than 70° F., and preferably higher. The road should have been resurfaced during the past four to six months. The surface should be thoroughly dry, and tar should not be applied before ten o'clock in the morning.

The surface should be free from dust and dirt, and where possible the surface should be lightly washed with a hose and water under pressure, and the road allowed to dry with traffic excluded for two or three days. The tar should be heated to 140° F. and spread very evenly, avoiding excess, and well brushed into the surface voids. Two or three hours should be allowed for the tar to be absorbed, and then a light even coating of sharp sand should be spread over it. The quantity of tar should be regulated according to the capacity of the road for absorption, and should not be less than .25 gallons or over .5 gallons per square yard. Two light coats are recommended as more efficient than one heavy coat. No essential modification has resulted in seven years work with this method.

The most important specification is that of the choice of the day for doing the work. It is absolutely essential that the weather should be clear and warm, and that the road should be thoroughly dry, not only on the surface but down into the body

for several inches. This means that at least two days of dry, clear weather should have elapsed since the last rain, and that June in this latitude is about the first month that successful results may be expected, due to the excess of moisture absorbed during the winter and spring rains, and September is probably the latest. The necessity of observing the proper weather conditions, and the shortness of the season, naturally increases the cost of work when done by contract, as the men and plant are idle so much of the time, but with highway commissions the men can generally be utilized in other work, so that it is not so important.

FIG. 13.



French tar distributing machine.

Considering the practical application of this method, we find here that freeing the road from dust is the most difficult and expensive part of the process; but this is due to the fact that in France, and, to a very considerable extent in England, they keep the surface of their roads free from mud and dirt by frequent scrapings and brushings, so that the preparation for the application of tar is not so difficult, while here only in the case of a few turnpikes, parks, or closely settled suburban villages, is such a thing ever thought of, so that it requires a great deal more labor on our roads to remove the accumulated dust. Again,

owing to the fact that our horses are nearly all shod with caulks, the surface is continually kept rough, and thus affords lodgment for the road and traffic dust, while abroad the horses are smooth shod, or when caulks are used at all it is only in cities, so that the road surface is smoother and easier cleaned by brushing, which would ravel an American road. The preliminary sweeping is usually done by hand in France, and by horse sweepers in England and America, reinforced by a hand gang who clean out any hollows or depressions not reached by the larger and stiffer revolving broom.

FIG. 14.

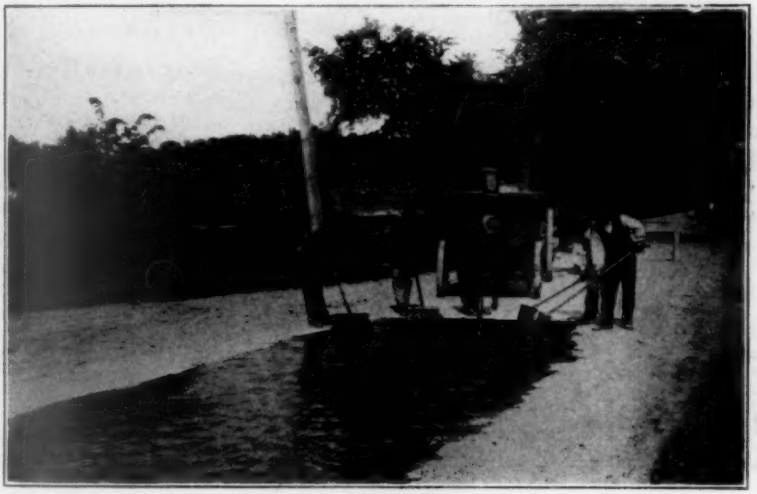
Lassailly tarring machine.

This sweeping is of the greatest importance, and lack of care with it is responsible for the majority of the failures, even where the other conditions have been carefully observed. There are two main reasons: When the surface voids are filled with dust, the tar collects in little globules and does not penetrate the road metal at all, just as water assumes the spheroidal state on a hot iron plate, and is readily washed away at the first rain. Again, when a quantity of dust is allowed to remain in the bottom of any little hollow or chuck hole, the excess of tar that will nearly always collect there forms a cake with an apparently smooth surface, but under the action of the weather and the traffic this soon disintegrates and is licked out by passing wheels, leaving the metal unprotected, so that moisture penetrating under the tar surface soon destroys it for a considerable distance around

the original hollow, giving the road a very bad appearance and soon forming deep chuck holes.

The tar has been applied in a number of different ways. At first and in small jobs it was heated in kettles on the roadside, and applied from hand sprinkling cans provided with wide flaring nozzles. A small tank holding about fifty gallons, on wheels, that could be pulled by two men, was then used in France. Nozzles were provided, so that an even distribution was secured. This was succeeded by portable horse-drawn boilers that would hold a number of gallons, but the actual sprinkling was done by hand

FIG. 15.



Distributing and brooming-in tar

with a flat nozzle connected by a flexible hose so that the quantity of tar used could be more accurately apportioned to the requirements of the surface. About 1906 the Lassailly machine was invented, which sprinkled the tar at a predetermined rate, and made use of a set of automatic brushes to secure a more uniform distribution. In the United States the usual form of street sprinkler has been provided with an iron tank (that would remain tight under the influence of the hot tar) and the sprinkler has been modified to handle the thicker substance, while the White oiling machine has been adopted to some extent.

Probably the very best work has been done by a skilled man distributing the tar from a nozzle, as he can gauge precisely just how much tar each separate section requires, but, of course, at much greater expense than with the machines, where the flow must be more or less uniform regardless of requirements.

Following the actual spreading of the tar come men who follow the sprinklers with brooms and brush it thoroughly into the road metal. They see that it is spread evenly and remove any excess and cover the thin places. Their work is very important, as it is difficult when the dust has not been completely

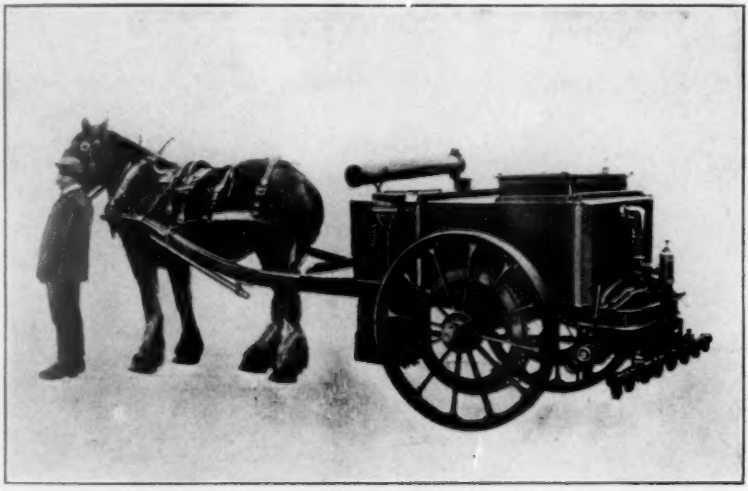
FIG. 16.

Road treated by first method, Savannah, Ga.

removed to make the tar "take" on the surface, that is to break down the surface film that is formed and really penetrate the interstices of the metal. It was to overcome this difficulty that the use of water as a preliminary washing was recommended; but, of course, this is not always practicable as the road must be closed to traffic while it is drying. The water removes the surface dust film and leaves the stone in very good condition to receive the tar. It is essential also, for the reasons given above, that no excess of tar should be allowed to collect in puddles in hollows in the road surface. Stable brooms are generally used, and about one man for each 3 feet of width of road, with an

extra man or two bringing up the rear to remove any puddles, etc., that have escaped the regular gang. The men here frequently work so that they brush towards the body, by standing on the untreated road, but in France they are provided with wooden shoes and brush away from the body, walking in the tarred surface. The latter seems much the better method, except from the nuisance to the men. On the smoother road surfaces of France they frequently use a rubber squegee to spread the tar after sprinkling; this seems to give very good results there, but does not seem adapted to the rougher surface of our roads.

FIG. 17.



Horse-drawn tar-spraying machine

This brooming or sweeping in is a very disagreeable and hard work if it is done properly, as the tar must be thoroughly brushed and rubbed into the road metal to secure the best results. It seems to take weight to do this, and the men can't keep it up properly for very long at a time. They frequently arrange the work so that the gangs change places about every hour.

The surface should remain undisturbed for several hours to allow the absorption of the tar, and then be lightly covered with a clean, sharp sand just sufficient to absorb any of the tar remaining on the surface and to fill the voids which were opened by the sweeping.

This method has been widely used in France, and has proven very successful with their smooth surfaces, but it is necessarily slow and expensive at the higher rates of labor in England and America. In order to obviate the labor cost, and to avoid the necessity of heating the tar, some modifications have been made to it.

About 1905 they commenced applying the tar cold after thinning it with tar oils, and in order to avoid the labor necessary for sweeping and spreading, a number of machines have been invented to spray the tar on the road under pressure. These meth-

FIG. 18.

Power tar-spraying machine.

ods come under the second heading, and are known in general as "tar painting." The preliminary sweeping need only remove the larger particles of debris as the pressure of the tar forces it through the dust. The uniformity of the machine's action allows a very much smaller quantity of tar to be used and yet secure a continuous coating, while the brooming afterwards is entirely done away with; moreover, the work is done about twenty to thirty times as rapidly, thus enabling more work to be done during the most suitable season. This method has been widely used in England with both coal gas tar, and almost en-

tirely now with water gas tar, and has given generally satisfactory results.

The machines in use are—

Aitkens Pneumatic Tar Sprayer is the inventon of Mr. T. Aitken, County Surveyor of Cupar-Fife in Scotland. It is made in two forms, one with steam drive and the other for horse-power.

Pumps geared to the wheels compress the tar to a pressure of 100 to 150 pounds when it is atomized with air under a pressure

FIG. 19.

Spreading and rolling screenings.

of 100 to 150 pounds in nozzles, into the road surface. The power machine has steam coils so that the tar may be heated, but with the horse-drawn vehicle the tar must be used cold or heated before being put into the tank. The Tarspra discharges the tar under a pressure of 200 pounds, and has pumps to keep up this pressure and the delivery of the tar constant. These machines are now made by the Taroads Syndicate of London, England. There are, of course, a number of other machines, but these seem to be the most important.

The introduction of these machines has enormously increased

the use of tar for road treatment in England, and I believe that it would be of equal benefit here, as it does away with a great deal of labor and applies the tar quickly and economically.

To better adapt the application of tar to the rougher surfaces of our American roads, the third method has been evolved and which seems to give the best results under our conditions. The work is all done exactly as under the first method, except that a considerably heavier refined grade of tar is used, that has more body and greater binding properties, and it is applied about twice as heavily. Then, instead of sand, a light coating of clean gravel or fine stone chips is put on, and the whole surface is rolled with a road roller. This treatment renews the wearing surface and fills the voids made by sweeping very much better than the sanding, while it also (from the heavier tar used and greater quantity) seems to penetrate more deeply, and its effect is more lasting. It succeeds best on Macadam roads. It is practically mud-proof; absolutely free from road dust; apparently proof against very heavy motor traffic, and under American conditions is by far the most satisfactory surface treatment. Its cost, however, is very much higher than either of the two other methods. In this connection it will be considered later with respect to other methods.

Considering now some of the details regarding the proper quantities of materials necessary, we find that they are dependent almost entirely on the condition of the surface to be treated, and they may be tabulated as follows:

MATERIALS.

	Tar gals.	Sand tons.	Screenings.
	Per sq. yd.	Per sq. yd.	Tons per sq. yd.
Method No. 1. Smooth roads	.20—.30	.006	
Rough roads	.30—.40	.009	
Method No. 2. Smooth roads	.12—.15	.003	
Rough roads	.15—.25	.005	
Method No. 3. Smooth roads	.33—.45		.010—.015
Rough roads	.45—.65		.015—.025
Gravel roads	.60—.70		.025—.030

In general, a road when slightly damp will not absorb one-half the tar that it will when thoroughly dry, and the same holds with a badly swept road. Gravel will take more tar than Macadam.

In the selection of the tar for use as a surface coating, we must consider the conditions and the results that are desired. The first method was developed to utilize a dehydrated coal tar, and this seems to serve the purpose quite well, as it is intended not only to lay the dust but to serve as a waterproof coating for the road, but it was not expected that it should last more than one season, and the plan now seems to be to give two treatments a year. The tar should then have a fair body, and be free from ammoniacal liquor, as this prevents a proper penetration and has a disintegrating effect on the coating after being applied. Freedom from carbon is another advantageous characteristic, as it is the excess of free carbon that undoubtedly causes the black mud formation in winter.

In the second method coal tar thinned with tar oils, creosote oil or mixed with resin, or, best of all, water gas tar, seems to have given the best results. Here the principal effect desired is the dust laying, and as a number of coats are applied per season the tar does not require much body.

For the third process, which is expected to be very much more permanent, and which, moreover, is required to act as a matrix not only for the road metal proper but also for the surface layer of screening, a much heavier bodied tar is required. The material generally used for this purpose has been a dehydrated coal tar with nearly all the light oils (that is, up to 392° F.) removed, and sold under the trade name of Tarvia in this country, and Claires' Tar Comp. in England. During the past year compounds made from water-gas tar have been successfully used.

There are several patented foreign preparations for use in tarring roads. Among them, and probably the most widely used, is Claire's Tar Comp., a dehydrated coal tar preparation very similar to the American Tarvia; Solidified Tar, made by Tar Patents Co., of London, is simply coal tar dehydrated and treated with 4 to 5 per cent. of $H_2 SO_4$; Marbit, prepared by T. E. Marriott, of Glasgow, is crude coal tar and a specially prepared natural bitumen which are mixed and immediately applied.

The advantages of the surface treatment with tar preparations are, in general, as follows: (1) Freedom from dust. (2) Protection of the road surface from motor traffic. (3)

Lengthening of life of surface by waterproofing effect of tar. (4) More resilient surface for horses. (5) Freedom from surface wash, and less clogging of drains.

There are, however, a number of objections that have been urged against its application, particularly by the first two methods; this is using crude coal tar or tar painting with water or coal tar with machines. When a heavy rain follows an application of crude coal tar or tar painting, it has been found in some cases that fish in neighboring streams have been killed by the tar oils. This, of course, does not apply to the heavier tars used in the third method. The tarred roads have in some cases churned badly in winter, forming a very disagreeable black slimy mud. This dries out and the road regains its former appearance with dry weather. This is not so noticeable when water-gas tar has been used, which is low in free carbon and is less noticeable on road surfaces that are kept free from traffic debris; this does not apply to the third method. It has been found that with "tar painting" the surface does not stand skidding on curves.

The most important objection, however, is that lately brought up in Paris, where it was claimed that a number of trees had been killed by the tar used on the roads in the Bois de Boulogne, and that on this account they were going to discontinue its use. In fact, an article appeared in the September *Engineering Record*, which said that it had been decided not to tar on this account during the next season the seven main suburban roads leading out of Paris.

A considerable amount of discussion has resulted from these statements, and the English *Surveyor and Municipal Engineer* sent out a circular letter to all the county surveyors in England who had tarred roads, asking for their experiences. In general, there was not a single instance where any damage to trees or to shrubs could be directly charged to tarring the roads. Dr. Guglieminetti, who is probably the foremost authority, ridiculed the whole affair. He admitted, however, that there were several delicate plants that did not seem to bloom when planted close to roads used for fast motor traffic, that had been tarred. He advised that hardier flowers be used, and this has been done. The question was brought up at the International Road Congress, and the authorities in charge of the Bois de Boulogne denied that any trees had been directly injured by the tar, but

they did have trouble with some flowers. Moreover, the Congress went on record as favoring the use of tar.

It should also be remembered in this connection that tar has been used for years in treating parasitic diseases of plants and trees, without any evil effects resulting from its use. Again, we know that crude water-gas tar is very successful, according to Mr. Waring, of Omaha, in preventing the growth of grass and weeds in roads where it has been applied.

I feel that with both crude coal and water-gas tar there may be some danger if they are used in excess by the first two methods but I do not believe that there is anything to be feared from the use of the heavier grades of refined tars used in the third method, as no damage by this method has been reported publicly, nor has considerable inquiry revealed any existing.

The use of tar as a surface treatment is by far the most effective method for controlling the dust and preserving the road surface from motors, particularly when a heavy refined tar is used and a sufficiency of screening is rolled in, thus obviating the objections which have been raised to the first two methods mentioned.

It seems to give good results with varying road surfaces, but succeeds best with Macadam in good original condition.

However, any surface treatment must be looked upon as merely a palliative, and it is not a preventative in the true sense of the word, so that some more permanent treatment or method of construction is required.

INCORPORATING TARS IN THE MATERIAL OF THE ROAD.

The failure of the surface treatment to stand the strain of heavy motor traffic, especially on curves, and the desire for a more permanent road construction, led to the revival of the use of the so-called tar Macadam, which is a Macadam construction with the upper two to four inches of the stone embedded in a matrix of tar rather than the usual one of cementing rock powder. This is laid by coating the stone with tar before spreading and rolling.

It was apparently used at Nottingham, Eng., about 1840, and at Sheffield in 1845. It was introduced in Paris about 1854, Knoxville, Tenn., about 1866. The important use of it in street paving came about 1871, when the Snow and Davis patents

were granted. These required the use of H_2SO_4 to harden the tar used. The Filbert Vulcanite Paving also used a hardening material. From 1871 to 1878 about 750,000 square yards of this form of paving was laid in Washington, with the following results:

20 per cent. failed within 2 to 3 years.
30 per cent. lasted 7 years.
41 per cent. lasted 15 years.
4.9 per cent. lasted 20 years.
1.2 per cent. lasted 30 years.
Giving an average life of 12 years.

In 1877 machine mixing was introduced with improved results, and the same year it began to be used at Stratford, Ont., 1881 Hamilton, Ont., used it with conspicuous success; 1886 the influence of the asphalt companies caused its abandonment in Washington. In 1887 it was used at Ann Arbor, Springfield, and Topeka. From 1890 to 1894 a great deal was laid at Barre, Vt., Pawtucket, R. I., St. Johnsbury, Vt., and Littleton, Vt. In 1898 Woodsville, Vt., used it successfully. In 1901 the Warren Bitulithic paving was patented, and was widely used.

The subject now assumed more importance from the advent of the motor car and the necessity of more durable road treatment, and various modifications of the use of tars or oils in impregnating the upper wearing surfaces of roads, were evolved.

The California method of constructing dirt roads was used about 1903, and was patented by the Petrolithic Co. The Wafsworth system, using rock asphalt, was brought out in 1905. The Gladwell system was first used in 1906, and the Imperial road was patented the same year. In 1907 crude residue molasses was used at Newton, Mass.

There have been so many variations introduced into the construction of roads, with this general principle, that we will include all construction where the upper layers of the surfacing are saturated or coated with a bituminous substance, under this heading, and divide them into four classes: (1) Where the material is first coated, then spread on the surface and rolled. Including Bitulithic, Tarmac, Gladwell system. (2) Where the materials are coated in layers in situ, so-called penetration system. (3) Where the upper surface is harrowed, the oils worked in by mixing in the surface. The California system including Petrolithic and Imperial systems. (4) The use of rock asphalts.

In general, tar Macadam is laid as a wearing surface on any well drained and compacted foundation; an old road surface may be used, but usually a Telford, or preferably, a regular Macadam foundation is built up and the top 2 to 3 inches, or wearing surface, is made of the bituminous mixture.

The first method by mixing is the earliest, and still seems to give the best results, but at a considerably higher cost. The principal object is to insure that each particle of stone shall be

FIG. 20.

Mixing tar Macadam.

evenly and completely covered with the bituminous compound. This requires that the stone shall be dry and warm and well turned in contact with the tar mixture.

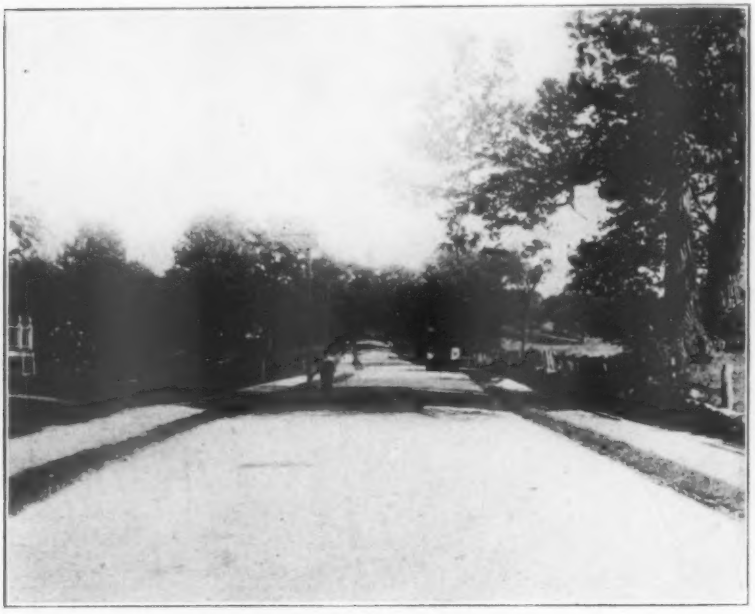
The earlier engineers heaped the stone on alternative layers with coke and breeze, and fired them after the manner of a lime kiln, then spread tar over the whole mass and turned it like concrete. This resulted in overheating some of the stone and burning the tar. Later the stone and tar were heated separately and mixed in hot iron plates, by hand, but machine mixing is now

used in all large pieces of work with the constituents separately heated.

The method in use at Sheffield, Eng., where tar Macadam has been in use over 40 years, is as follows:

On a Macadam foundation they put a one-stone layer of 2¼ inches limestone, and a one-stone layer of 1¾ inches slag, both tarred with a mixture of 110 gallons of tar boiled 2 hours, with 125 pounds pitch, used at the rate of 13 gallons per ton of

FIG. 21.



Spreading and rolling tar Macadam.

aggregate. A top coat ¾ inch of a mixture of ½ inch fine stone and ½ inch slag, tarred with 17.5 gallons of the mixture per cubic yard is put on, and the whole rolled until it is 4 inches thick. A light coating of clean ½ inch limestone chips is spread on the surface and rolled in.

The method used successfully at Hamilton, Ont., requires a 6-inch Telford foundation with 6-inch chamber, voids filled with smaller stones and well rolled. A layer of tarred 2½ inches stone is put on, and voids filled with tarred gravel; then a layer of

tarred 2 inches stone is rolled in. The top dressing is composed of two-thirds sharp fine gravel and one-third stone dust, mixed with 25 gallons of tar per cubic yard. This is put on about ½ inch deep, and after thorough rolling, is covered with fine dry stone dust and rolled again.

At Newton, Mass., during 1908, the Office of Public Roads put on a surface coating that seemed to give very good results, and which withstood the past winter very successfully. The

FIG. 22.

Finished surface, Newton, Mass.

old surface was picked up with a road roller and brought up to crown with No. 2 stone, and carefully rolled. A one-stone layer of No. 1 stone was then spread on the surface and rolled carefully with a 20-ton roller. About 2½ inches of a tarred aggregate composed of 960 pounds of 1½ to ¾ inch stone, 350 pounds of ¾ inch dust stone, and 6 gallons of the bituminous binder, on one portion of this work, a water-gas tar compound made by my company, was used. This aggregate was mixed hot like concrete, and after spreading was lightly rolled once. After 5

to 6 hours it was given two trips of the roller, and the next day enough crushed grit or tarred sand was put on to fill the surface voids, and the whole surface thoroughly rolled with a 20-ton roller. The road has the appearance of sheet asphalt, especially on the section where tarred sand was used as a top dressing; but it gives a better footing and does not cause skidding in wet weather.

In 1901 F. Warren patented a combination of graded broken stone and dust of different sizes, mixed with a bituminous cement, so that the stone mixture should have a very low percentage of voids. His original patent used six sizes of stone in varying proportions.

70 per cent. of stone passing 3 inches and on $\frac{1}{2}$ inch.
20 per cent. of stone passing $\frac{1}{2}$ inch and on $\frac{1}{10}$ inch.
4 per cent. of stone passing $\frac{1}{10}$ inch and on $\frac{1}{40}$ inch.
3 per cent. of stone passing $\frac{1}{40}$ inch and on $\frac{1}{80}$ inch.
3 per cent. of dust passing $\frac{1}{80}$ inch.
1 per cent. of dust passing $\frac{1}{200}$ inch.

One hundred parts of this mixture heated and mixed with six parts of bituminous cement. His argument was that such a mixture required the minimum amount of cementing material, which could, therefore, be made quite soft and have a longer life. He has since reduced the number of sizes of stones required and made some other improvements. Owing to the care used in selecting, mixing, and laying, and in the uniform quantity of the bituminous cement, the work done by the Warren or affiliated companies has given excellent satisfaction.

The extended use of tar Macadam in England has brought out a number of patented preparations. Tarmac was the earliest, and was invented, if it can be so called, by E. P. Hooley, Surveyor of Nottingham. It is now supplied by the Tarmac Co., of Ettingshall, near Birmingham. This is blast-furnace slag boiled in a tar pitch mixture and seasoned. It is prepared ready for rolling, and has been very widely used throughout England. The slag is carefully selected and graded so that the best results may be obtained. Tarfaat is a top dressing made of tarred powdered slag. Tarlithic and Granite are prepared mixtures of granite tarred and ready for spreading.

In this country the Sarco Road Compound (apparently a "blown oil" mixture) has been exploited for this purpose, and an extended trial was made on one of the Chicago Boulevards during 1908.

Another patented compound which gives promise of success is a prepared top dressing known as "Amiesite." This consists of crushed stone coated cold at the quarry with a hot mixture of 60 per cent. solid asphalt and 40 per cent. of a heavy asphalt oil. The mixing is done in a concrete mixer and after the stones are coated about half a bushel of slacked lime is added to each cubic yard. When this is worked in half a peck of dampened sand is added. The addition of the dampened sand prevents the particles of stone from adhering and enables it to be handled very easily.

FIG. 23.

Bitulithic pavement, Wilmington, Del.

The prepared mixture is spread on the clean Macadam foundation about 4 inches in depth and after a thorough rolling is ready for travel. Several experimental pieces of this road have been laid near Camden, N. J.

In general, it seems to cost from 25 to 33 per cent. more to lay tar Macadam by the mixing method than ordinary Macadam, but it should have from two to five times as long a life.

A variation of this general method is the Gladwell system, brought out by Mr. A. Gladwell, Eaton, Eng. It was first used during 1906 at Stoke Poges.

The old surface is carefully swept clean, and a ¾-inch layer of ¼-inch tarred granite chips are carefully and evenly spread

on. It is then covered with a two-stone layer of 2½-inch dry crushed stone, free from dust and chips. A light steam roller is now very slowly run over the surface to press the stones down into the tarred matrix and to draw the latter up to surface.

FIG. 24.

Laying Amiesite, Camden Co., N. J.

When the binder is seen working up to the surface a light layer of the tarred chips is spread over the top and brushed into the voids, the rolling is continued until the finished thickness is 2¾ to 3 inches thick, and the surface is compact. About one-sixth of a gallon of hot tar compound is sprayed or brushed over the

surface, and covered with ¼ of an inch of clean dry granite or trap screenings, followed by a roller. It is estimated that this method would cost 20 per cent. more than the ordinary Macadam in the United States.

In an endeavor to find a cheaper method of building a surface resembling that made by the mixing process, the so-called penetration process was used. This consists of saturating the different layers of stone composing the wearing surface after they

FIG. 25.

Amiesite, Magnolia, N. J.

have been placed on the road, by spraying or sprinkling the binder on them. This method was used as early as 1856–60 at Weston-super-Mére in England, but it did not attain much importance until it was brought out by Mr. Thos. Aitken in connection with his pneumatic spraying machine, for which purpose it is said to be eminently adapted.

The general method is to build up the road in the usual manner, except that no water is used in rolling; then just before the

binder course of fine gravel or screenings is applied, the surface is sprayed with the hot tar compound from a machine. The pressure used secures a penetration of from 2 to 3 inches. The layer of gravel is now rolled in, and the surface pores are filled with another light coat of tar, followed by dry screenings and rolling. The maximum binding value from the smallest quantity of tar is obtained at a minimum labor cost. The quantity of tar used per square yard of course varies according to the stone used and the traffic expected, but is usually at the rate of from

FIG. 26.

Tar Macadam by penetration, Wilmington, Del.

.7 to 1.0 gallons per square yard. In England it costs from 2 to 4 cents per square yard for this method over the ordinary Macadam, while here it would probably run from 6 to 8 cents.

A number of experimental pieces of road have been laid by the penetration method around Boston. At Newton, Mass., they pick up the surface to a depth of from 2 to 3 inches, harrow it, dress up to crown with No. 1 and No. 2 stone, and roll. Sprinkle 1 to 1.3 gallons of hot tar compound, and then spread on a light coat of screening and roll. The Metropolitan Park Commission

built a stretch of road especially for motor traffic, as follows: On a regular Macadam foundation, 4 inches of No. 1 stone, with a little fine gravel as a binder, is rolled in. Four inches of gravel is then spread on and 1.3 gallons of asphaltum base oil is sprinkled on it; a light coat of gravel is put on to absorb the surplus oil, and the whole is thoroughly rolled. Mr. Blanchard, of Rhode Island, made some experiments with this method, but he did not have the proper facilities for spreading the tar, so that his results were not satisfactory owing to the necessity of using too much tar.

FIG. 27.

Liquid asphalt, Blackwood, N. J.

Considerable work has been done in New Jersey with a so-called "Liquid Asphalt," a heavy asphaltic base oil containing 82 per cent. of asphalt oils. The oil was applied to the compacted 1½-inch course before the binder was applied. The ¾-inch binder and screening were then put on and rolled in. This road gave great promise up to the early part of this spring when with the coming of the warm weather the surface ravelled considerably and they are now applying a top dressing of gravel.

INCORPORATING OILS INTO THE ROAD SURFACE.

The peculiar climatic and soil conditions of California have developed methods for the construction of both earth and stone roads that are, in general, somewhat similar to a tarred Macadam, in that they surround the particles with a binder. When oil was

FIG. 28.

Petrolithic rolling tamper.

first used, they found that the surface application did not secure sufficient penetration for the best results, so other methods of incorporating the oil were devised. In Yolo County the road surface is cut out to the desired cross section with an 8-inch crown, and a hard even base is secured free from weak spots

About 1 gallon of oil per square yard is now put on, and the earth that was cut out is returned to a depth of 4 to 5 inches. This is then rolled and travel is permitted. As the oil works to the top, a grader and drag are run over the surface, and more soil is brought on. This is repeated until the oil fails to work out, and results in a very cheap construction, costing only $150 per mile.

FIG. 29.

Tamping—Imperial construction.

The Petrolithic system of building roads was started about 1903, and was a development of the earlier systems. In Santa Monica, Cal., the system is as follows: After grading, the surface is plowed 4 inches deep with a turning plow, clods are pulverized and the surface is cultivated and harrowed until it is of a uniform consistency. About 1 gallon per square yard of hot asphalt base oil of 12 to 15° B., and containing not less than 70 per cent. of D grade asphalt, is put on. If the soil is light or sandy, .15 gallon more is put on. This is thoroughly cultivated and harrowed in, and another coat at the same rate is put on.

The surface is then turned under with a 4-inch plow and thoroughly harrowed along the length and diagonally. It is then cultivated to an even grade and sprinkled. A rolling tamper is then applied; this weighs about 1500 pounds, and has iron pins set in its surface about 7 inches long with heads about 2 x 3 inches. There are fifteen pins arranged in 12 rings, or 180 in all. This is run over the road until it is thoroughly compacted to within an inch of the surface. About 1½ to 2 inches of

FIG. 30.

Imperial—putting on stone surface, Westville, N. J.

gravel is spread on the road and mixed carefully with the surface soil, and from 1 to 1.5 gallons of hot oil are sprinkled on. The surface is again harrowed and then tamped until it is solid. A very light layer of fine gravel is put on, and the surface is smoothed with an ordinary steam roller.

A very similar type of road is being exploited under the name of Imperial Paving; this is laid under the patent No. 833,551, granted in 1906,and in general they plow up the original

surface, stones or dirt, harrow it, apply the binder, an asphalt oil under 40 pounds pressure, harrow again and compact with a rolling tamper, which consists of a number of toothed disks in a shaft, the teeth being about 4 inches deep. The roller weighs 3 tons. This tamping is continued until the whole surface is hard. Gravel or stone chips are put on, and the surface smoothed with a ten-ton steam roller. Some of these roads in Kansas

FIG. 31.

White road-oiling machine.

City, Mo., have been very satisfactory, but generally this type of construction has not been very successful under our Eastern climatic conditions.

Several useful forms of machinery have been developed in connection with the use of oil in road building that might serve a useful purpose with tar. The White oiling machine has already been mentioned. This has a large number of openings that are controlled by levers in sections 18 inches long, so that 18 inches or any multiple of this width can be treated or cut off by the operator. The DeCamp machine is adapted for oiling

dusty roads. It has three sets of plungers similar to a corn planter. It opens a furrow, puts the oil at its base, covers it up and then stirs it. The White Sanding machine distributes an even layer of sand in a road surface. It uses an apron feed geared with the wheels, the depth of sand on which can be accurately regulated.

Related to this construction is the use of oil in consolidating sand roads. This was successfully tried in Massachusetts in 1905–6. The surface was dressed up and .75 gallon per square yard was put on at 180° F. and allowed two weeks to be absorbed; .75 gallon more were put on and the surface was harrowed, rolled, and sprinkled lightly with sand. The next year .76 gallon per square yard was put on, and about .0024 ton per square yard of stone screening was rolled in. The surface is said to be very good, and the cost was 27.76 cents per square yard.

During 1908 the Office of Public Roads made an experiment on a Gumbo clay road at Independence, Kan., using an artificial asphalt. It was found difficult, however, to make the soil absorb the asphalt satisfactorily, but this might have been avoided possibly to some extent by cutting back the preparation with a crude oil to reduce its viscosity.

In general, I do not believe from the results so far obtained, that the methods using the asphaltic base oils will ever achieve complete success in this latitude, owing to the fact that the binder in the surface course seems to lose its life after a winter's exposure to the alternate hail, snow, heat, and cold of the climate in this latitude.

A method accomplishing much the same results as tar Macadam, is the use of natural asphalt rock from Kentucky, and applied under the trade name of Wadsworth Macadam. This was first used commercially in Kentucky in 1905. The specifications recommended by the distributors of the asphalt rock are as follows: "Shape and roll the dirt bed thoroughly as if a regular Macadam or asphalt pavement were to be constructed. Next, place and roll a 6-inch layer of good crushed stone, about 2½-inch size. Then spread a 2-inch layer of 2-inch stone, and on this second layer of stone, before same is rolled, spread an inch of Kentucky rock asphalt, and after again thoroughly rolling, the road is ready for traffic."

The Office of Public Roads in 1907 made an experiment with

this material at Bowling Green, Ky. The road had an 8-inch gravel surface over a Telford foundation; this surface was spiked up to a depth of 4 inches, and brought to a camber of ½ inch to the foot by removing the excess gravel. This subgrade was carefully rolled. Four inches of 1½- and 1-inch stone was spread evenly over the surface, and rolled once to turn down the sharp edges and leave an even surface. One and one-half inch of the asphalt rock was then spread on, breaking up the lumps and filling all the voids as much as possible. The roller was then kept moving parallel to the axis of the roadway, running off occasionally to dust the roller to keep it from sticking. After about the fifth rolling the surface began to compact as the rock came to a firm bearing. It was found that the rock could not be worked below 70 to 75° F., and worked better as the temperature increased. The road rutted quite badly when traffic was first allowed on it, but by the end of a week these all disappeared and the surface had become smooth and compact. The surface was elastic, yet self-healing from any ruts or dents.

While it is admitted that with a proper tar Macadam construction we secure a wearing surface that is dustless, resilient, proof against motor traffic, easy to clean, though expensive, yet there are several objections that must be considered.

The most important one is that of grade. In general, it has not been found wise to use it on grades greater than 3 to 4 in a hundred, owing to the fact that horses seem to have trouble with footing. This is especially apparent during frosty weather in the early morning. On curves in wet weather it has been found to increase the tendency to side-slip with motors. It seems that these effects are caused by an excess of tar on the surface when an insufficient quantity of dry screenings were applied, or they were not rolled in properly and were then picked out by the traffic.

The most important points in favor of this type of construction are the facts that it is absolutely waterproof, and is, therefore, free from frost action, and that all the stone particles are held rigidly in position so that there can be no internal attrition.

SELECTION OF MATERIALS.

In considering the selection of materials for use in making tar Macadam, their availability is, of course, the primal consid-

eration, but where several grades of stone are near at hand, it has been found that a rough, regular fracture seems to give the best results. The harder the stone the better, although blast furnace slag has given good results when properly chosen.

As to size, this is dependent somewhat upon the thickness of coating that it is desired to lay, and the largest size in the mixture should apparently be about ½ inch less than the finished thickness of the layer.

In general, we desire to lay a dense mixture, and this involves either grading the stones before mixing, or by spreading layers of the different sizes and then making a homogeneous mixture by rolling the stones together on the surface.

There are two general methods in use for making dense stone aggregates for cement concrete work where a minimum percentage of voids is of even more importance than in our work. The one consists in using the maximum quantity of the largest size stone, and then filling the voids by the use of a large quantity of very fine mortar, any particle of which will enter the voids in the large stone. The other method brought out by Mr. W. D. Fuller, proportions the stone by the parabolic formula where

$$d = \frac{P^2 D}{10000}$$

d = any given diam.
P = percentage of mixture smaller than this diam.
D = largest diam. of stone used.

Two curves are given for 2-inch and 1½-inch stone, the sizes usually used for tar Macadam.

Mr. Fuller combines his stone mixtures after mechanical analyses, so that they most nearly approach this curve.

For instance, with 1½-inch stone as the largest size, he requires that—

92 per cent. shall pass through 1½ inch sieve.
82 per cent. shall pass through 1 inch sieve.
70 per cent. shall pass through ¾ inch sieve.
57 per cent. shall pass through ½ inch sieve.
42 per cent. shall pass through ¼ inch sieve.
25 per cent. shall pass through $\frac{1}{10}$ inch sieve.

This might be approximated then by

30 per cent. 1½ inches to ¾ inch.
28 per cent. ¾ inch to ¼ inch.
42 per cent. ¼ inch to dust.

However, in this work we generally require a greater proportion of the large stone. Considering the quantity of voids in

the different size stone that we might use, it will be found that they will vary with different classes of rock, depending on its cleavage and fracture, hardness, kind and adjustment of crusher.

The following figures * may be of service:

HARD TRAP, ROTARY CRUSHER.

Size of stone.	Per cent. of voids loose.	Per cent. of voids, compressed.
2½ inches to 1 inch.	54.5	43.7
1 inch to ¼ inch.	54.5	42.8
2½ inches to dust.	45.0	30.6

SOFT TRAP, JAW CRUSHER.

Size of stone.	Per cent. of voids, loose.	Per cent. of voids, compressed.
2 inches to ¾ inch.	51.0	40.6
¾ inch to ⅛ inch.	51.0	35.9

GRAVEL.

Size of stone.	Per cent. of voids, loose	Per cent. of voids, compressed
2½ inches to ¼ inch.	36.5	28.2
Sand	34.0	27.0

Assuming now a percentage of voids in the compressed stone of 43 per cent. and in sand of 27 per cent., the following would give a dense mixture:

Pounds.	Material.	Volumetric percentage.
1000	1½ inches stone.	60.0
430	¾ inch dust stone.	25.7
189	Sand.	11.3
22	Bituminous cement.	3.0

While this mixture would have, theoretically, a low percentage of voids, yet as the surface of the particles which must be covered by the bituminous binder rises very rapidly as the size of the particles decreases, considerably more bituminous binder is required. It is found that about 10 per cent. by volume of the stone mixture should be cement. This would give then

Pounds.	Material.	Volumetric percentage.
1000	1½ inches stone.	60.0
400	¾ inch dust.	24.0
100	Sand.	6.0
74	Bituminous cement..	10.0

If it is desired to use only two sizes of stone, the following mixture might be used:

Pounds.	Material.	Volumetric percentage.
1000	1½ inches stone.	66.5
370	¾ inch dust.	24.5
60	Compound.	9.0

* Quoted in Taylor and Thompson's "Concrete, Plain and Reinforced."

A similar mixture was used in some Government experiments at Newton, Mass., very successfully. In some sections tarred sand was rolled into the surface, which gave a very smooth finish.

The question of the selection of a proper binder for this work and the specifications for different qualities, has been the subject of considerable scientific and practical inquiry and experiment during the past three years.

At the present time there are two committees from scientific societies, viz.: The American Society of Civil Engineers, of which committee Mr. W. W. Crosby, Chief Engineer of the Maryland Geological Survey, is chairman, and Prof. M. H. Blanchard, Assistant Engineer of the State Board of Public Roads of Rhode Island, is secretary, and The American Society for Testing Materials, whose Committee on Standard Tests for Road Material is headed by Mr. Logan W. Page, Director of the Office of Public Roads, as chairman, and Mr. Prevost Hubbard, Assistant Chemist of the Office of Public Roads, is secretary. In view of the fact that both of these committees will present reports during the coming summer, only a general survey of this question will be given.

The materials in general use at the present time consist wholly, or as mixtures, of coal tar, water gas tar, coke oven tar, asphaltic base oils, both crude and residue blown oils, sulphate pitch and a number of natural bitumens, such as Gilsinite, etc.

It is not difficult to see that with such a collection of materials bidding for public favor, that a proper choice would be a difficult one. In general, the asphaltic oils and residues have given very much better results in warm, dry climates, such as California and the South, than in our damper and colder northern climate. Here the various tar preparations have been more successful.

Crude coal tar was used in the earlier experiments, but it was soon found to yield better results when partially refined, especially when the ammoniacal liquor and some of the light oils were removed.

Water gas tar was first used in 1904–5 at Omaha, Neb., and at Tunbridge Wells in England, as a dust-laying treatment, known now as "tar painting." It proved very successful, as it had the following advantages over the coal tar formerly employed. (1) It was cheaper. (2) Being more fluid, it could be applied cold.. (3) It penetrated the surface more readily.

(4) It resisted wet weather better, and seemed to churn less in winter. (5) It contains very much less free carbon than coal tar, which probably accounts for advantage 4.

The success attending its use as a dust layer led to trials of its use as a surface treatment with screenings, but the crude water gas tar did not contain sufficient binder, and they were not successful. During the past two years, however, a refined grade of tar has been prepared which unites all the advantages of penetration and resistance to moisture and churning with the toughness and strength of the other preparations. The exceedingly low percentage of free carbon in the water gas tar preparation is undoubtedly the cause of its superior behavior.

The question of the percentage of free carbon is already recognized as important, and nearly all specifications restrict it. At the coming meet of the American Society for Testing Materials, Mr. Prevost Hubbard will read a paper on its influence on bituminous materials for road work.

In general, it acts as diluent while giving the material a false vicosity. So that in one pound of material there would be from 18 to 25 per cent. more active binder (material insoluble in CS_2) in a water gas tar pitch than a coal tar preparation.

Furthermore, the free carbon seems to exercise a hydroscopic property, tending to absorb moisture, which has a deteriorating effect on the coating and is undoubtedly responsible for the churning that sometimes occurs in winter.

The question of specifications has been gone into very thoroughly by Mr. Prevost Hubbard, of the Office of Public Roads, in Bulletin No. 34, entitled "Dust Preventatives," some brief abstracts for different materials being given at the end of the paper.

In general, I believe that we require a compound that, while developing the greatest binding property, will not become too fluid at high temperatures, that it will run under a summer sun, and yet will be elastic enough not to become brittle and crack at the winter temperatures. To this must be added a further proviso, that it shall not contain such a percentage of volatile oils that their loss under the exposure to the elements during its use in the road will impair either its strength or elasticity. This could be secured by specifications which would require at certain temperatures dependent upon the climate of the locality, certain

binding strengths and viscosities, together with a maximum allowable loss in the vaporization test, which consists in heating a standard weight of the material at some fixed temperature for a definite time while exposing a fixed surface.

The question of the perfecting of a machine that will give accurate figures for the breaking strength is, of course, the important one, and is now occupying the attention of the members of the two Committees mentioned above. It may be necessary to briquette the material with a standard sand, but in any event, the breaking load will undoubtedly have to be applied as a sudden shock, and the breaking strength recorded on some form of spring balance.

CONCRETE SURFACING.

There are several methods of road construction that have lately been brought into notice in an endeavor to find a surface that should be dustless and withstand heavy motor traffic, and although they are not in any way related to the subject, we feel that they should at least be briefly mentioned. They are the use of cement surfacing and small granite or composition setts.

Concrete road surfacing was probably introduced by J. Mitchell at Inverness, Eng., about 1865, when he patented a cement concrete for this purpose composed of:

Broken stone, 4 parts.
Sharp sand, 1¼ to 1½ parts.
Portland cement, 1 part.

The surface was to be laid in two layers 7 to 8 inches deep in all. In general, the chief objection to concrete surfaces for road purposes is the fact that they crack badly from temperature changes, and afford but little foothold for horses. In the form of paving which was introduced in Bellefontaine, O., in 1896, and is now exploited as the Hassam pavement, covered by U. S. Patent No. 819,652, they endeavor to prevent cracking with a metal reinforcement. There has lately been introduced an acid wash for concrete surfaces that attacks the surface coating of cement and exposes the aggregate, thus giving a better footing, so that these two objections may in time be overcome. Cement surfacing has been tried at Toulouse and Grenoble, France, but without notable success. A great deal of it was put in at Panama, where it is said to be quite successful, but its high cost,

$2.00 per square yard, precludes its use for anything but city streets. At Newton, Mass., they tried a surface grouting of concrete on a Macadam surface, but it scaled badly and eventually had to be abandoned.

At the Brookfields Track, a motordrome in England, the concrete surface that was first used failed so badly under the action of heavy racing cars at a speed of from 80 to 100 miles per hour, that it had to be nearly all replaced. The surface seemed to lose a thin surface skin, and then the concrete failed, like Macadam, ruts forming to a depth of several inches.

On the Motor Parkway, in Long Island, where the Vanderbilt Cup Races are held, the Hassam paving was used, but so far it seems to have withstood the effects of both winter weather and the high speed. However, much of this parkway is on tangents and fairly flat, while at the Brookfields Track it is nearly all on a curve and steeply banked. Again, the speed at Brookfields was considerably higher and the machines were heavier.

SETS.

There are three forms of block, or set, paving that have considerable promise.

Nonskidamacrete is a compound block formed under pressure with a cement concrete base and a tar Macadam top. They are laid on a concrete or Macadam sub-base, and are held in place with a tar grouting. They have not been in use long enough to gain an insight into their durability, but they are said to be cheap, noiseless and all that their name implies.

Dorrite is another block paving made by compressing a tarred gravel with 20 per cent. of tar into 4-inch blocks, with a pressure of 2½ tons per square inch. This is a German invention, is laid as the Nonskidamacrete, and is also an experiment.

Kleinpflaster is a random block made by a patented machine from granite. It was first introduced at Stade, near Hanover, Germany, in 1885. The blocks are laid on a ½-inch bed of sand over either a concrete or Macadam foundation. The blocks are usually 2¾- or 3½-inch cubes, and are laid as closely as possible, then well tamped and any joints brushed with sand. They afford a good foothold, and seem to last 20 years under heavy traffic. They cost in Germany $1.50 per square yard in place.

A later modification of this is the Durax, the distinctive

feature being that the blocks are laid in segments of a circle with chords of 5 to 6 feet, at right angles, to the centre line of the street. This is said to make the paving quite noiseless. The blocks are now grouted with an elastic tar preparation, and cost about $1.50 a square yard in England.

Captain Bingham, of the Royal Commission on Motor Traffic, in England, declared that this was the best and most economical method of obtaining a strong, noiseless, non-skidding and dustless road surfacing for all kinds of traffic. This method does not seem to have been used as yet in this country.

GENERAL REVIEW.

In considering the subject of road treatment generally, and the application of tars or oils in particular, there are four general factors that must be taken into consideration:

1. The climatic conditions.
2. The road surface, *i.e.*, material and condition.
3. The traffic which the road has to bear.
4. The money available.

The methods, as mentioned before, which were originated in a hot, dry climate, cannot be expected to yield the same excellent results in cold, damp ones. Again, some considerations such as foot-hold and spalling from frost need never be considered in uniformly warm parts of the country. The asphaltic oils have generally failed in this latitude, but have been successful elsewhere, while water and coal gas tar pitch has given satisfactory results.

In considering the question of the influence of the present road surface in general, asphalt oils have given better results on gravel, and tars on Macadam. It would obviously not pay to tear up a good Macadam surface and lay tar Macadam, but it should be tar painted or tarred with screening until ready for resurfacing, and then rebuilt as a tar Macadam road. The same would apply to gravel. If, however, the road was badly ravelled but not too deeply worn, it might be resurfaced by the penetration method with good results.

With sand or clay roads some modification, which would result in a thorough admixture of the binder with the soil, followed by thorough compacting, seems to be the most advisable. While asphalt oils have hitherto been used almost exclusively, yet I

believe in this latitude a proper tar compound would give much more successful results.

We feel that a more intelligent inquiry into the possible traffic that a surface may be expected to bear would frequently prevent failure from the use of unsuitable materials and methods. Frequently the traffic of a road is considered and reported as very light pleasure traffic, when a careful survey will reveal quite the opposite.

A traffic census made on June 20, 1908, on a street in Montclair, N. J., gave 6.5 tons per foot width per hour, while a busy street in Newark, N. J., gave only 4.0 tons. The Montclair street was paved with Macadam, and was not designed for heavy traffic, while the Newark street was paved with Belgian blocks set on concrete, probably the strongest paving possible.

The great number of motor cars that are yearly increasing must be considered whenever any new construction is contemplated, as the entire travel is usually diverted to each new road even at a sacrifice of several miles in distance. Again, it would doubtless pay to consider the possibility of paving certain points, where travel is concentrated or unusually severe conditions are to be expected such as the approaches and crossings of main roads, sharp curves and the approaches to sharp grades, with a more permanent form of paving and use a cheaper form on the tangents and lesser traveled portions.

However, the determining factor is usually, how much will it cost, and not how long will it last? In the majority of our rural communities there is a large mileage of road that is always just about to become impassable—something must be done to keep them open to travel, so that a little is spent here and there and no permanent good is secured. In some few instances in the older settled sections where the road system has been more completely developed, the main problem is one of maintenance, and it is here that we find a more intelligent view prevailing of the wisdom of doing each piece of work thoroughly. Of course, the American practice of " working out " the road tax is responsible for the lack of money with which to make permanent improvements in the roads, but the feeling is gaining ground that in many cases it will well repay a borough to issue bonds for this purpose, putting in some permanent form of construction that will give the benefit of good roads, while the money that was

formerly spent in maintenance will more than pay the sinking fund charges.

Two very good papers on the most economical method of procedure from a financial standpoint have been written by French engineers, who, of course, are concerned principally with the cost of maintaining their present roads, as I believe the French National Road system is now complete. P. Caufourier, in *Le Genie Civil,* vol. lii, No. 16, p. 268, goes into the question of the probable life of the road under various treatments and different intensities of travel, and he gives some equations which, when the proper constants are assumed, will show the economical method to be used. His general conclusions were that tar painting was only economical with very hard material under heavy travel, or with very poor material under light travel. That tarring with a coat of hard screening was good with heavy travel on poor surfacing. That tar Macadam was good in heavy travel even with poor metal. That frequently when there is but little difference in the annual charge, it will prove more economical to use the better (more permanent) method.

Another article published in the *Annales des Ponts et Chaussés,* part 5, 1908, plots curves showing the annual costs at 4 per cent. interest for various classes of paving, thus showing the different life that each should attain to be equally economical. However, these tables apply only to French conditions, but they show that there is a growing desire to consider the matter of road finances in a more scientific manner.

Mr. H. P. Maybury, a prominent English road engineer, in reviewing the arguments for and against tar Macadam, feels that in his district, where they have some snow in winter and it is quite hilly, and where the present surfacing is granite, that on account of the slipperiness of tar Macadam in winter, the danger of using it in hills, its first cost, together with some little traffic dust in summer, that it is not the best, even under the heavy motor traffic. He suggests building a very deep, strong surface with a flat camber of not over 1 to 30, using large hard stone (2½- and 2-inch granite) for the surface, with just enough small stone to fill the interstices, and grouted with tar, keeping the dust down with machine tar painting, as the best solution of the problem short of some form of Kleinpflaster or Durax paving.

The First International Road Congress agreed that a firm,

well drained foundation was the first essential; that tar properly applied as a surface application would lay the dust and protect the road from light motor traffic, but that for heavy motor traffic the surface material to a depth of 2 inches should be mixed with the binder.

We may say for a tar treatment properly applied that it makes a road:

Dustless;
More hygienic;
Less troublesome and expensive to keep clean;
Less mud;
No water cuts;
More pleasing to travel over from its resiliency;
Less expensive in the long run to maintain.

The Office of Public Roads made a census of the roads of the United States in 1904, with the following results: Total mileage of public roads, 2,161,570; of this 7.14 per cent. were improved roads.

108,233 miles of gravel.
38,622 miles of stone.
6,810 miles of shell, oil, etc.

153,665

During the five years just past there has been a great awakening in the interest in good roads, and from the 1908 Report of the Office of Public Roads we now have

124,468 miles of gravel road.
43,450 miles of stone road.
8,512 miles of shell, oil, etc.

176,430 miles of improved road.

Leaving out the 8,512 miles of shell and oil road, we have 177,000 miles of recognized improved road.

In England and Wales there are

23,826 miles of main road.
95,211 miles of side road.

119,037 miles.

On these roads England is spending, practically in maintenance alone, $347 a mile on main road and $107 a mile per year on the side roads.

In France the length of roads and annual expenditure per mile are as follows:

National roads,	22,009 miles	$230 per mile.
State roads,	16,188 miles	180 per mile.
Important town roads,	128,522 miles	130 per mile.
Village roads,	155,093 miles	55 per mile.
Total,	321,812 miles.	

Average per mile=$102.00.

We are spending less than $40. But our roads are in the building, and the next forty years will see an enormous increase in the mileage of good roads. We already have State aid laws in 23 States, and during 1908, 16 States spent $18,000,000 and built 1,800 miles of new road. When we consider that in districts where the roads are improved, the attendance of school children is 77 per cent., while in those districts where poor roads prevail it is only 53 per cent., and that from the best figures obtainable the American farmer is spending from 13 to 25 cents per ton mile more than he should on every load he hauls to the railroad station, we cannot but feel that the country as a whole will awaken to the soundness of good roads as an investment, and that we will, as a nation, soon excel the world in the matter of improved roads. They cannot be built in one year nor ten, but if the movement is even properly started nothing can keep it back.

With the increasing use of motor cars some form of surface treatment is absolutely essential to preserve the integrity of a Macadam surface. It has been universally admitted that tar properly treated and applied fulfills this purpose admirably.

REDUCED DIAMETER CARD COMPASS.

INFORMATION has been received by the Bureau of Manufactures that a patent reduced diameter card compass has just been exhibited in Liverpool and caused great interest to people concerned in British shipping, its value being described as follows:

It appears in many respects a desirable improvement on the compass now generally used, especially by securing the card magnification of the markings without eye-strain, and by permitting the use of cards of small diameter as compared with that of the ordinary compass. It also affords greater steadiness and freedom from that inertia which is associated with cards of full diameter in use at the present time. For many years the desirability has been recognized for adopting some suitable means of enlarging the markings or calibration of compass cards to enable helmsmen to readily detect any deviation from the course. Hitherto it has been a common practice for seamen to use ordinary lens magnifiers, or have large compass cards provided.

Compasses with 12-inch and 15-inch cards have been used, but there are disadvantages connected with them on account of their unsteadiness in a seaway owing to the period of vibration and inertia, hence they have not

been altogether successful. Lens magnifiers are only used to a limited extent, as they cause the same strain to the helmsman's eyes as a result from the use of strong spectacles, and the lenses have to be fitted on the compass glass, which is said to be undesirable. The reduced diameter card compass invention has been brought out with the object of doing away with the disadvantages referred to. There has been introduced to this compass an arrangement whereby the markings or calibrations of the card can be increased to almost any size without any of the drawbacks encountered in the ordinary compass.

CLOSER AND MORE ACCURATE STEERING OBTAINED.

In this invention a magnifying mirror, which is adapted to magnify the markings on the card to any desired extent, is placed inside the compass bowl on the forward part so that the top of the compass may be removed without affecting the mirror. To the compass card is added a down-turn rim on which the degrees are marked, the figures being reversed so that they show normally in the magnifying mirror. Instead of the steersman viewing the compass card direct, he steers by the magnified image shown in the mirror, and the least movement of the vessel is at once detected. Closer and more accurate steering, it is alleged, is attained by the new card compass, as the slightest deviation from the course is immediately observed. As the helmsman is viewing the magnified reflection and not the object directly through the magnifier, there is no straining of the eyes, in fact the strain is said to be considerably less than when steering with the usual 10-inch card now so extensively used. The inventors say that exhaustive practical tests have been made at sea under all weather conditions with results which have undoubtedly insured the success of this new magnifying system of steering. Navigational experts to whom this patent has been shown expressed their approval of the practical advantages of it, and recognized the convenience it afforded to seamen.

LITHOGRAPHIC STONE INDUSTRY.

SMALL GERMAN TOWN FURNISHES THE WORLD'S SUPPLY.

The quarrying and preparing for market of lithographic stones is a unique industry carried on near Solenhofen, about 45 miles south of Nuremberg, on the main railway line to Munich. The town is an unimportant one of about 1,300 inhabitants, the stone quarries being in the hills back of the town at a level of some 1,500 feet above the sea.

So far as is now known, the area in which these stones are found is not more than 4 or 5 miles long by 2 or 3 miles wide. In this limited area quarrying has been carried on for more than a century, and from it practically the world's supply of lithographic stones has been obtained.

The stone, as is well known, is a species of compact limestone of peculiar texture and of a yellowish-gray or bluish-gray color, hard bluish stones being the more valuable. It is found in layers varying in thickness from a half inch, or even less, up to 6 or 7 inches. The layers extend from near the surface of the ground to a depth of 75 or 100 feet, or even more, and are apt to be much broken by fractures or seams and layers of worthless rock and earth.

SMALL PERCENTAGE OF MARKETABLE STONE.

In the best quarries not more than one-twelfth of the material removed is marketable stone, and much of this is of little value because of the small sizes in which it can be found clear of cracks or flaws. The quarrying is carried on by several different firms and by a corporation. About 1,200 workmen are employed in the various quarries and in the work of cutting and dressing the stone for market. The stones are lifted carefully from their

position in the quarries in various marketable sizes and are then hauled to buildings near by. Here the surfaces—for some markets one and for others both—are ground down, chiefly with coarse sand rubbed on by heavy machines, water being constantly applied during the process.

One concern has recently introduced a heavy machine fitted with a carborundum planer, which rapidly smooths the surface of the stones as they are passed back and forth under the planer, somewhat as heavy plank in a planing mill. The stones are further smoothed by machinery and by hand, the edges being neatly trimmed and corners rounded.

If the stones are 6 inches or 7 inches thick when taken from the quarries, as is sometimes the case, they are sawed through once by heavy saws fitted on the edges with diamonds and operated by steam power. The finished stones vary in size from 6 by 8 inches to 44 by 64 inches, and vary in price, when ready for shipment, from 15 or 20 cents up to $65 or $70, depending upon the size and quality. In recent years the thinner stones which would break under the pressure to which they are subjected in printing, are, in some cases, securely cemented to other stone slabs, thus giving the requisite strength.

It is a notable fact that the industry has never been a source of great profit to those engaged in it. The explanation is that the amount of dead work in the quarries is large, and the proportion of perfect stone of marketable size is so small as to leave little margin of profit at the prices at which the stones are sold. It frequently happens that after a stone has been ground smooth, or perhaps been sawed through at considerable expense, a chalky vein, small pebbles, or other defects appear in the surface, greatly lessening its value. These defects become apparent when a damp sponge is passed over the surface of the stone.

FUTURE SUPPLY.

Those interested in the lithographic-stone industry say that the demand for this product has not rapidly increased in recent years. At the present rate of quarrying they believe the supply at Solenhofen should last for from 100 to 200 years, or even longer. The stones are at present exported to all civilized countries of the globe. Germany is the largest buyer; France, Italy, England, and the United States are the next in importance in the order named. The declared values of the exports of lithographic stones to the United States for the eight years beginning with January 1, 1900, were as follows:

YEAR.	VALUE.	YEAR.	VALUE.
1900	$105,949	1904	$149,316
1901	131,632	1905	124,719
1902	135,010	1906	157,118
1903	138,000	1907	161,905

—*Consular Report.*

CORRESPONDENCE

THE INTERIOR OF THE EARTH IN THE LIGHT OF THE NEW SEISMOLOGY.

SECRETARY OF THE FRANKLIN INSTITUTE:

In the JOURNAL OF THE FRANKLIN INSTITUTE, June, 1909, I published an article on Earthquakes in the Light of the New Seismology. My object was to present in a systematic way the latest facts about Seismology that have been learned by such workers as John Milne, Lord Kelvin and other recognized authorities; in order to make the article educative I presented the facts in such sequence and in such a way that the layman as well as the scientific man could understand them.

In the September number of the JOURNAL OF THE FRANKLIN INSTITUTE under correspondence are some criticisms by Mr. H. W. Hixon on the views about the condition of the interior of the earth. It is true I used the quotation in my article "An open-minded hospitality for new facts is essential to intellectual advance;" this is correct, every one has a right to his opinions on scientific questions, and discussions sometimes point out errors. I also used the quotation "many like to have a theory on which they can rely implicitly and regard as final; they dislike to sum up evidence and suspend judgment until sufficient evidence is collected."

Surely I was liberal in my article. I gave the four views or hypotheses about the interior of the earth and discussed them briefly, while Mr. Hixon apparently relies implicitly and regards as final one theory, namely, the earth has a crust about 200 miles thick (diameter of earth 8000 miles) and all the rest of the interior of the earth is gaseous. In his letter he gives a definition of critical temperature and states it may be true enough to found a theory on and then gives his reasons for the hypothesis that the earth is a globe of gas confined by a thin crust.

In none of our standard works on geology such as Dana, Le Conte, Scott, Salisbury and Chamberlain and in none of the monographs, annual reports or Bulletins of the United States Geological Survey, all of which are warmly praised by European geologists or in the standard geologies of England, such as Geikie and Prestwich, can the author recall any reference to such a theory. In an article by Mr. Hixon on "The Relation of Magmatic Waters to Volcanic Action" (see JOURNAL OF THE FRANKLIN INSTITUTE, October, 1908) is opened by this sentence, "The relation of magmatic waters to volcanic action, ore deposition, mountain folding and kindred phenomena has not been fully appreciated and with few exceptions has not been recognized as of any importance."

According to Mr. Hixon's statement we can understand why he practically stands almost alone with this hypothesis, when he acknowledges it has not been recognized as of any importance. It is not a final argument against Mr. Hixon's hypothesis that he stands almost alone with it. Other men in the past have stood alone, but in these days when there is such an open-minded hospitality for facts rather than theories, there must be something radically wrong with such an hypothesis when it receives no recognition or even slight mention by geologists generally.

The reason for Mr. Hixon's letter of criticism of the various views on the interior of the earth in my article on Earthquakes is very clear to me. I say various views because none of the four hypotheses are original with

me. He saw clearly that the facts proved by Milne and Lord Kelvin practically put his first article on volcanoes out of commission.

His article on "The Relation of Magmatic Waters to Volcanoes" and his paper on earthquakes are practically the same throughout. One is simply a repetition of the same theories as the other; even the same diagram is given, so that if he had said these views may also apply to earthquakes the reader would have understood.

Lord Kelvin proved very clearly that it would be impossible for the earth to have a thin crust and a gaseous interior. He demonstrated mathematically that a crust or shell of solid steel 500 kilometres (312 miles) thick would yield under the enormous pull of the sun and moon as if it were India rubber. If a shell of steel 312 miles thick would yield like India rubber, what would happen to a gaseous earth covered with a thin crust? It would undoubtedly be pulled out of shape. Astronomers fully realize that the earth behaves as a solid rigid body in space and not as a gaseous globe or even a molten globe with a thin crust.

In the Transactions of the Royal Society for 1863 is an article on "The Rigidity of the Earth" by Sir Wm. Thomson (Lord Kelvin). In this article he makes very clear his opinions and proofs in regard to the solidity and rigidity of the earth. He says "The tidal effective rigidity of the earth may be both several times as much as that of iron (which would make the phenomena of both tides and of precession and nutation sensibly the same as if the earth were perfectly rigid). It is enough that the actual rigidity should be several times as great as the actual rigidity of iron throughout 2000 or more miles thickness of the crust." He also states in the same article on "The Rigidity of the Earth:" "The earth cannot, as many geologists suppose, be a liquid mass included only in a thin shell of solidified matter, as demonstrated by the phenomena of precession and nutation.

Mr. Hopkins, to whom the grand idea of thus learning the physical condition of the interior from the phenomena of rotational motion presented by the surfaces, applied mathematical analysis to investigate the rotation of rigid ellipsoidal shells enclosing liquids and arrived at the conclusion that the solid crust of the earth must be not less than 800 or 1000 miles thick" (see Transactions of the Royal Society, 1839, 1840, and 1842.).

Lord Kelvin confirms this opinion and goes farther when he says: "It has always appeared to me that Mr. Hopkins might have pressed his argument further and have concluded that no continuous liquid vesicle at all approaching the dimensions of a spheroid of 6000 miles in diameter can possibly exist in the earth's interior without rendering the phenomena of precession and nutation very sensibly different from what they are."

That the opinions about the solidity and rigidity of the earth have not changed during the lapse of time can be seen by consulting Thomson and Tait's Natural Philosophy, Part II, 1903, "Tidal Influence of the Sun and Moon on the Earth." "Had the solid part of the earth so little rigidity as to allow it to yield in its own figure very nearly as much as if it were fluid, there would be nearly nothing of what we call tides; that is to say rise and fall of the sea relatively to the land; but the land and sea would rise and fall a few feet every twelve lunar hours. This would, as we shall see, be the case if the geological hypothesis of a thin crust were true. The actual phenomena of tides, therefore, gives a secure contradiction to that hypothesis, even a continuous solid globe of the same mass and diameter of the earth would, if homogenous and of the same rigidity as glass or as steel, yield in its shape to the tidal influences three-fifths as much or one-third as much as a perfectly fluid globe." Again on page 439 is found the statement: "Rigidity of the earth unless greater than that of steel would be very imperfectly effective in maintaining its figure against tide generating force." It is not necessary to multiply examples; those who are interested enough to follow such a discussion farther will find interesting reading in the following articles:

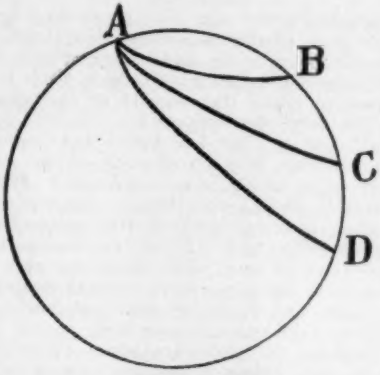
Result of "Tidal Effective Rigidity of the Earth," by Prof. Simon New-

comb, see monthly notices of Royal Astronomical Society, vol. lii, No. 5, 1892; "Age and Solidity of the Earth," by Clarence King, formerly Director U. S. Geological Survey, see American Journal of Science, third series, vol. xlv, 1893; Prof. George Darwin on "Tides," Transactions of Royal Society, 1879, Part II.

Enough has been quoted to show that scientific men are opposed to the thin crust and molten interior view and much more to a gaseous interior view. Prof. Milne proved very conclusively that the earth is not a globe of gas with a thin crust. I will quote from my article on earthquakes to prove it:

"*Distant earthquake waves travel straight through the solid elastic earth below the crust.*" This is probably the most important discovery made in recent years in seismology and one which the general public and some of the writers of text-books have not grasped as yet. It is doubly important from the fact that notwithstanding that the study of the different theories about the earth and its interior is a very obscure subject, this proof of Milne's helps us to eliminate and discard the thin crust and molten interior view and also the theory of a solid crust and solid interior with a pasty or viscous layer sandwiched between (more than all the others does it eliminate from

FIG. 1.



discussion the thin crust and gaseous interior view). It is very evident that an earthquake wave requires a solid and elastic medium for its propagation and it could not travel from Japan to England below the crust through a molten mass which is not of course solid or elastic. (Much less could it travel through gas.) And it is also very evident that if we consider the pasty layer view in reference to this proof of Milne's, it will not hold because the earthquake wave would have to pass through two pasty layers before reaching England, neither of which is elastic or suitable for the propagation of earthquake waves.

Now what proof has Milne that the earthquake wave travels through the solid earth first and not around the crust? Namely this: He says for example if an earthquake wave were to travel from Japan to England through the crust around the circumference we would get two messages—the one travelling through the shortest arc of the circumference would arrive first and the one coming the longest distance would arrive later, because the waves would travel in both directions. Now as a matter of fact we only get one message through the solid earth travelling along the chord of an arc. We are indebted to articles by Milne and also to an excellent interview by Cleveland Moffett with Milne for the interesting and popular way in which some of these facts are set forth. For example:

If an earthquake starts at *A* (Fig. 1) it travels through the solid earth first from *A* to *D* through the cord *AD*, also from *A* to *C* and *A* to *B*. The others and later waves travel along the surface from *A B C* to *D* a considerable time afterward. It travels through the solid elastic interior much more rapidly than it does through the fissured crust. All the waves from far distant earthquakes reach the Isle of Wight in practically the same time they travel from Japan, Borneo and Java to England—in about 16 minutes. Milne says that an earthquake wave from Borneo reaches England in nearly the same time that one from the West Indies does and Borneo is nearly 2000 miles further away. This he says is due to the fact that the wave from Borneo travels through the earth at a much greater depth than the wave from the West Indies and consequently it travels much faster because the earth at a greater depth is much more elastic and rigid.

Earthquake waves that start at the opposite side of the globe, travel much more quickly than those that start on our side of the globe, because they travel deeper through the more rigid elastic interior. In fact the shock of a nearby earthquake may reach us through the crust. (*In view of the above facts that Milne has proved, can anyone conceive of an earthquake wave travelling through gas? In spite of any theory or mathematical calculations, here you have absolute proof that the interior of the earth is not gaseous.*)

Lord Kelvin regretted years ago that there was not sufficient reliable data about the velocity of earthquake waves for short distances. He said it would be invaluable in proving facts about the solidity of the earth. Since he made that statement seismographs have been invented and a great mass of data accumulated about the velocity of earthquake waves not only for short distances but from the antipodes.

Mr. Hixon says "The gaseous interior is but a remnant of a gaseous planet and must have within it some of each of the gases which diffused throughout the planet when in a gaseous condition." Have we any evidence that this is the case? It so happens that we have abundant evidence, but that it has heretofore been misapplied and misunderstood. The gases given off during earthquakes and volcanic explosions have been observed and in the following selected cases will show that they play an important part in both phenomena. He then gives several examples of earthquakes to show that fissures open and discharge mud and sand together with hydrogen sulphide, sulphurous acid and carbonic acid.

Unfortunately most of the examples given of earthquakes took place from 100 to 150 years ago, before seismology was a science. Earthquakes have only been studied scientifically for about 50 years. It would be difficult to prove the kind of gases that issued from fissures 150 years ago, although it is possible that some of the data is correct. We have but few reliable records to-day of the various gases that are said to issue from fissures during earthquakes, simply because they are not collected and analyzed and the odor may not be decided. One of the first examples cited by him is rather unfortunate: "In the month of October, 1755, several strange meteorological phenomena occurred in the Spanish peninsula, such as frequent halos around the sun and moon, numerous luminous meteors and terrific thunderstorms with much rain. The waters of both wells and rivers became turbid and fetid, rats and reptiles came forth as if frightened and domestic animals showed much uneasiness. On the first of the following month of November occurred the great earthquake of Lisbon."

He says an explanation of all these strange phenomena except the luminous meteors is to be found in the effect of the escaping gas, such as sulphuretted hydrogen, sulphurous acid and carbonic acid from the interior as premonitory symptoms of the coming shock. "The cause of alarm of all animals living in burrows or holes," he says, "is easily explained, as the gases would reach their smelling organs and alarm them. The same is

true of dogs and domestic animals that keep their noses on or near the ground, while man that walks on his hind legs does not think of the gases as coming from the ground and is not so quickly warned as the lower animals."

Modern meteorology does not recognize any connection between halos, meteors and thunderstorms, and from the phenomena of earthquakes this is too evident to require proof and simply shows the state of the earthquake science 150 years ago.

It does not require an odor to drive animals from burrows; a shock or jar is sufficient. Man to-day would probably recognize an odor that would not disturb an animal. Perhaps if man was ever arboreal and cavorted around the tree tops he would then fail to recognize it; there doubtless are cases where gases have driven animals from burrows.

Prof. W. H. Hobbs of the University of Michigan, an authority on earthquakes, in his book recently published, page 78, says: "Fissures are channels for the transmission of gases emitted at the surface; such gases are generally highly charged with sulphuretted hydrogen due to the decomposition of animal and vegetable matter in the soil and are disengaged by the local fissuring." According to this, Prof. Hobbs has very little faith that these gases come from a gaseous interior, as Mr. Hixon believes, and force their way through a molten magma of many feet in thickness, strangely enough without being decomposed by heat or without combining with the numerous elements with which they readily form compounds even at much lower temperatures. Sulphuretted hydrogen would surely form metallic sulphides if it passed through a molten magma, not too hot, where many elements were present.

It is entirely unnecessary to assume that these gases came from a gaseous interior and then force their way through molten rock and various elements many feet in thickness and finally came to the surface through crevices. It is needless to invoke an extraordinary supposition when a simple one will do. England's eminent astronomer, Sir Robert Ball, made this clear when speaking about the polar caps on Mars, he said: "I do not mean to affirm that it is universally admitted by astronomers that the polar caps on Mars are really ice and snow which they most certainly appear to be. It has even been conjectured that the white material may be solid carbonic acid gas. I must say however that it has always seemed to me rather perverse to invoke so extraordinary a supposition and one without any known parallel in nature, when water is immediately available to give a most satisfactory explanation of what has been observed."

The tendency to give extraordinary explanations of simple facts is too common in science to-day and should be avoided. The decomposition of organic matter, that is, animal and vegetable matter in the crust of the earth, is sufficient to explain the formation and occurrence of sulphuretted hydrogen and carbonic acid gas.

Milne in his book on earthquakes, page 153, says: "The gas eruptions which occasionally take place with earthquakes are probably due to the opening of fissures communicating with reservoirs or strata charged with products of natural distillation or chemical action, which previously had accumulated beneath impervious strata. Of the existence of such gases we have abundant evidence. In coal mines we have fire-damp which escapes in increased quantities with a lowering of the barometrical pressure. In volcanic regions we have many examples of natural springs of carbon dioxide.

Volger has attributed the origin of lights or flames appearing above fissures to the friction which must take place between various rocky materials at the time when the fissures are opened. In confirmation of this he refers to instances where similar phenomena have been observed at the time of landslips. At the time of these landslips the heat developed by friction has been sufficiently intense to convert water into steam, the tension of which has thrown mud and earth into the air like the explosion of a mine. (O. Volger, Unters. üb. d. Phän. d. Erdb., vol. iii, p. 414.)

Some of our petroleums are highly charged with sulphur compounds. The Lima oil, for example, was worthless for illumination until a process was discovered that would eliminate the sulphur compounds. This was a deep-seated unsuspected oil found in an old geological horizon. The sulphur came of course from the animal and vegetable matter from which the oil originated. This is mentioned to show one form of organic matter containing sulphur interbedded in the strata.

We believe that sulphurous acid gas or sulphur dioxide is more likely to occur in fissures near volcanoes produced by burning sulphur or burning of sulphuretted hydrogen which during combustion, forms water and sulphur dioxide. It is well here to remember that our stratified rocks are thousands of feet in thickness and they were laid down in ancient seas that swarmed with myriads of polypes, shell life, and fish as well as other forms of life. Enormous deposits of vegetable matter many feet in thickness may be found accumulated in the shallower waters, so that it does not require any extraordinary supposition to explain the origin of carbon dioxide and sulphuretted hydrogen in rocky strata or fissures—or even in springs.

Le Conte in his Compend of Geology, under Density of the Earth, states: "The mean density of the earth taken as a whole is 5.6, the density of the crust is about 2.5, therefore the density of the central parts must be very much greater than 5.6. It is probably not less than 15 or 16. This greater interior density is due partly to a difference of material (the denser settling toward the centre while the earth was still in a fused condition) and partly to condensation by pressure." If this is correct and the density of the interior is between 15 and 16, then that interior is certainly not gaseous.

An excellent opportunity to prove Mr. Hixon's supposition was the San Francisco earthquake. This was investigated by Mr. Gilbert, of the U. S. Geological Survey, and other able geologists, who reported the earthquake due to the slipping on the plane of an old fault. The fault was several hundred miles long, trending northwest and southeast. The movement which took place along this plane was horizontal. In simple language, there was a fissure extending across California for more than 300 miles from the southeast to the northwest. This fissure through ages became filled and the walls cemented together. All California geologists knew of the existence of this fault as well as others equally large. The fault-scarps along the coast as well as inland had been photographed and the line of faults traced on the geological maps.

What happened was that the fissures reopened for a distance of 300 miles and the walls slid horizontally from two to sixteen feet, so that a fence crossing the fault would be no longer continuous and part of it would be transported several feet beyond the remaining part. The depth of this fissure is unknown, but fissures of that length have profound depths. The bed-rock was shattered to great depths and some of the secondary cracks were so wide that one could look down several yards.

According to his theory one might have expected from an enormous pressure at such depth great volumes of sulphurous acid, carbonic acid, and sulphuretted hydrogen forcing their way up from the interior through a molten gaseous magma. From an inspection of Bulletin 324, U. S. Geological Survey, "The San Francisco Earthquake and Fire," we fail to find any mention of gases. According to Professor Lawson, the California geologist, page 16, the coast of California is rising, and the seismic disturbances whose record is found on the rocks have been produced by movements in the process of upheaval and subsidence, of folding and faulting, which are perhaps greater along the coast of California than in any other parts of the world. Whatever may be the causes of these movements, it is apparent that the resultant stresses relieve themselves by producing these faults or rifts in the earth's surface.

Mr. Lawson already states that the coast of California is rising and the frequent earthquakes are due to the walls of old fissures sliding or readjusting themselves, or to new fissures opening. These stresses and strains

are characteristic of a country that is rising. We must remember that elevation of this character is gradual, about a foot or two in a century; it is not a sudden spasmodic jolting producing an upheaval.

In a discussion of gases that escape through earthquake fissures chemistry plays as important a part as physics. If my critic had consulted an ad chemistry he would have learned that it would be impossible for sulphuretted hydrogen gas to come from a gaseous interior of the earth and pass through a molten magma having a temperature, according to his article on volcanoes (JOURNAL OF THE FRANKLIN INSTITUTE, 1908, page 299), of about 9000 degrees Fahrenheit, or 5000 Centigrade. Unfortunately for the theory he advances, sulphuretted hydrogen is not a very permanent gas but is decomposed at a low temperature about 400 degrees Centigrade. We see from this that sulphuretted hydrogen could not exist at such a high temperature, hence could not come from the source he says. A high temperature decomposes and destroys sulphuretted hydrogen so that it is simply impossible to come from a gaseous interior and force its way through a molten magma of enormous temperature. It is out of the question entirely; it could not exist at a very high temperature.

The same facts hold true in regard to sulphur dioxide. It will withstand a higher temperature than sulphuretted hydrogen without being destroyed, but not such temperatures as those stated. As we pointed out before, this gas, sulphur dioxide, is produced by the combustion of sulphur or sulphuretted hydrogen near or on the fissures of volcanic regions, according to the simple reactions:

$$S + O_2 = SO_2$$
$$2H_2S + O_4 = 2H_2O + 2SO_2$$

It is not a deep-seated gas and does not come from the interior, as Mr. Hixon states. This is a well-known fact and does not require any farther statement, even if it comes from the same fissures as sulphuretted hydrogen.

Another indication that it would have been well to consult chemistry before urging such a theory, is found in his article on volcanoes before referred to. On page 301 he says: "Before proceeding farther it is advisable to understand what we mean by steam at a temperature of 5000 degrees Centigrade and pressure of 45,400 atmospheres which corresponds to a depth of 100 miles." Unfortunately again for the theory, steam cannot exist at such a high temperature without being decomposed into its two gases, hydrogen and oxygen. H. Sainte Claire Deville proved that steam undergoes decomposition into hydrogen and oxygen at a temperature between 1100 and 1200 degrees Centigrade. This phenomenon is known as dissociation; so that the high temperature mentioned for steam in his article on volcanoes is not correct. Steam is also decomposed at a high heat by many elements, metallic and non-metallic, which combine with the oxygen to form oxides. Even water is decomposed by some elements at a comparatively low temperature.

Carbonic acid gas, or carbon dioxide, is one of the products of decomposition or decay of organic matter. Its origin is well known and seldom questioned. Mr. Hixon states that it comes from a gaseous interior of the earth and passes through the molten magma which has a temperature of 9000 degrees, yet Sainte Claire Deville states that this gas begins to decompose at 1300 degrees Centigrade, and Mallard and Le Chatelier say that at 1800 degrees the decomposition is distinct and rapid. It is very evident then that this gas would not come through a magma having that temperature, because it would be decomposed.

Mr. Hixon states that it is appropriate that his paper on earthquakes advocating the gaseous interior view of the earth should appear in the JOURNAL OF THE FRANKLIN INSTITUTE, because Benjamin Franklin believed in the gaseous interior hypothesis. When my late colleague, Prof. Albert H. Smythe wrote the life of Franklin in ten volumes he showed me another

life of Franklin which gave his views about earthquakes and the interior of the earth. He held the thin crust and molten interior view. Professor Smythe pronounces his views very crude and states that the best of his geological papers in his letter to Abbé Soulavie on the theory of the earth, September 22, 1782 (see Life and Writings of Benjamin Franklin, by Prof. A. H. Smythe, vol. i, p. 54.) Franklin says: "I therefore imagine that the internal parts of the earth might be a fluid more dense and of greater specific gravity than any of the solids we are acquainted with, which therefore, might swim in or upon that fluid. Thus the surface of the globe would be a shell capable of being broken and disordered by the violent movements of the fluid on which it rested." Mr. Hixon's error probably arose from the fact that the word "fluid" at the present day may mean a liquid or a gas. During Franklin's time the meaning was more restricted and it meant a liquid,—for example, they spoke of fluidextracts of substances. Franklin believed in the thin crust and molten interior hypothesis.

It was Arrhenius who first called attention to critical temperatures existing within our globe and thought the fluids would become dense gases on account of the heat and slightly compressible and viscous. Arrhenius assumed a core of gaseous iron nucleus the dimensions of which are four-fifths of the earth's radius. The reason for selecting iron or gaseous iron as a nucleus of the given size is that it would account for the density of the earth as a whole.

While the subject of critical temperatures within the earth may be a subject primarily for the physicist, and while the facts that we know about critical temperature have been learned on the surface of the earth, with surface conditions and pressures at our command, we are of the opinion that we cannot reason by analogy and say what the conditions of gases would be under a pressure of 200 or even 400 miles of rock. We cannot conceive of such pressures, and while we may have our opinions, as a matter of fact we know but little about the subject. It seems like begging the question to say the interior of the earth is gaseous and on account of the enormous pressure the gas behaves like a solid and has the properties of a solid; better say at once that it is a solid. In order to favor their hypothesis they make the gas have the properties of a solid so that the well-known facts about the rigidity of the earth and the density also can be explained. The crustal movements of the earth would probably be spasmodic and fearful to contemplate if the crust of the earth were floating on a gaseous interior. Earthquakes would be more frequent and appalling, and it is not likely that the growth of mountains would be so slow as it is to-day—only a foot or two in a century.

After the above answer to Mr. Hixon's criticism on the various hypotheses about the interior was written, I learned that Prof. J. Milne, since he wrote his two books on earthquakes, has modified his former views about the interior of the earth and now inclines more to the first view,—that is, the thin crust and molten interior, parts of which may be gaseous. Any one interested in this subject has had ample opportunity to become acquainted with Mr. Hixon's views from his two articles in the JOURNAL OF THE FRANKLIN INSTITUTE. In the journal may be found the opposite views advanced by others and myself.

Any continuance of this discussion would seem unnecessary as it would merely be a repetition of views fully given in the journal. The study of the interior of the earth is a very obscure subject and will continue to be, inasmuch as it is hidden from our view. We will still have to maintain an open-minded hospitality for new facts, until sufficient data is accumulated, if that time will ever arrive, to determine which of the several views advanced by geologists, physicists and astronomers is the correct one.

OSCAR C. S. CARTER.

[The views of the contributors having been presented at length, the Editors deem it inexpedient to devote additional space for further discussion.]

FRANKLIN INSTITUTE

(*Proceedings of the stated meeting held Wednesday, September 15, 1909.*)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, September 15, 1909.

JAMES CHRISTIE, Temporary Chairman.

Present, 60 members and visitors.

Additions to membership since last report, seven.

Mr. Henry E. Birkinbine presented a communication entitled "A Trail through the Mountains of Southern Mexico" and was followed by Mr. John Birkinbine who spoke on "Mexico, Its People and Its Industries." The speakers gave an interesting account of the country, its inhabitants, industries and resources and exhibited numerous lantern slides from original photographs.

After thanking the speakers the secretary declared the meeting adjourned.

JAMES CHRISTIE,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS

(*Abstract from proceedings of the stated meeting held September 1, 1909.*)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, September 1, 1909.

DR. E. GOLDSMITH, Temporary Chairman.

The following report was presented for first reading:

(No. 2431.) The *Isostigmar Lens.*—R. & J. Beck, London. (An advisory Report.)

In the absence of a quorum the reports for second reading were not presented for consideration.

R.

BOOK NOTICES

CANADA, DEPARTMENT OF MINES, Mines Branch. Report on the Iron Ore Deposits at Nova Scotia. (Part 1) by J. E. Woodman. 226 pages, illustrations, plates, maps, 8vo. Ottawa, Government Printing Bureau, 1909.

The report covers the more important iron deposits of the province. The scope and economic importance of the work may be judged from the detailed instructions given to the author, who was requested to give special attention to:—

Localities of iron ore deposits so far discovered, and names and addresses of owners; history of development of mines and companies (if any); geological description; analyses of ores; in cases of mines which have been worked, output and statistics; transportation facilities; limestone in neighborhood of deposits; state in general terms character of forest in neighborhood, *i.e.*, whether the supply is sufficient for mining purposes and for the production of charcoal in the event of the introduction of electric smelting; maps of mines (and drill holes, if any).

The report is divided into two main parts:

Part I deals with the geographic relations of the deposits, their mineralogy and geology, and questions relating to mining policy, bounties and mining laws.

Part II is entitled "Details of Iron Districts," and covers more particularly the ores of the Clementsport basin, the Nictaux-Torbrook field, the deposits of Hants and Colchester counties, the ores of the Western Cobequid mountains and of Arisaig, and the ores of Cape Breton and is replete with analyses of ores, records of bore holes and geological sections, and other statistical data.

In view of the present condition of the iron ore industry of Canada and particularly Nova Scotia, where so much imported iron ore is being used, this report should be of special value to mining engineers, investors and others interested in the development of the iron resources of this province.

R.

CANADA, DEPARTMENT OF MINES, Mines Branch. Bulletin No. 1. Investigation of the Peat Bogs and Peat Industry of Canada, during the season 1908–9 by Erik Nyström and S. A. Anrep. 25 pages, maps, 8vo. Ottawa, Government Printing Bureau, 1909.

The importance of the peat fuel industry to the central portion of Canada, where coal fuel is non-existent and its importation so comparatively costly, requires no demonstration.

The Department of Mines, Ottawa, issued a year ago a report on "Peat and Lignite, their Manufacture and Uses in Europe," with the object of

giving to Canadians as complete a review as possible of this industry in those countries in which it has been most successfully carried on.

This report is now followed by the above-mentioned bulletin which comprises 25 pages of text, and includes 6 large scale maps of the following peat bogs:

The Mer Bleue, near Ottawa; the Alfred Peat Bog, about 40 miles from Ottawa; the Welland Peat Bog, about 6 miles north of Welland; the Newington Bog, on the New York & Ottawa Ry., and about 40 miles from Ottawa; the Perth Bog, a mile and a half from Perth; the Victoria Road Bog, about a mile from Victoria Road station on the Midland division of the Grand Trunk Railway.

The bulletin contains a descriptive report of each bog, showing the location, area and structure, and giving an estimate of the available supply of peat fuel with records of analyses, calorific values, etc., and should be of particular interest to those engaged in, or connected with, the development of Canadian peat resources.

A fuel testing plant is now being erected at Ottawa, in which the value of peat for the production of power gas will be demonstrated, and the Department proposes to carry on a very thorough investigation of this subject.

R.

PRACTICAL METHODS FOR THE IRON AND STEEL WORKS' CHEMIST. By J. K. Heess, Easton, Pa., The Chemical Publishing Co., 1908. 60 pages 8vo. Cloth, price $1.00.

This book groups together in about 60 pages many of the methods which are used in routine furnace and mill analysis with special reference to decreasing the time involved rather than with reference to accuracy. Unfortunately the principles of English have in many instances been disregarded to such an extent that the meaning of the author is obscure.

The book gives tables and general information which will be useful to the steel works' chemist.

R. J.

LA SYNTHÈSE DES PIERRES PRÉCIEUSES. Par Jacques Boyer. Paper, 30 pages, 5½ x 7½ inches, with 6 full-page illustrations. Paris: Gauthier-Villars, 1909.

The imitation of Nature's method of the production of precious stones has always been an alluring problem alike to the alchemist and to the modern exponent of synthetical chemistry who has a thousand-and-one refinements of modern science at his command. Though the latter has made progress the problem is far from solved. In this little pamphlet the author gives an historic outline of the modern phases of the subject and the present state of the art, describing the methods and apparatus of recent investigators.

The subject is discussed under three distinct divisions: Synthesis of rubies and attempts at the reconstruction of the sapphire; Artificial reproduction of quartz, the opal, and the emerald; Synthesis of the diamond—which has been reproduced only in minute sizes.

A bibliography is appended.

L. E. P.

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